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# INHIBITION.

OUR positive knowledge of inhibitory phenomena, and still more our speculative forecasts, more or less closely dependent upon such added knowledge, have of late years greatly extended themselves. The term itself, first used to denote the now familiar phenomenon of cardiac inhibition, has expanded far beyond its original clear boundaries, to include, not merely all cases where one positive action is arrested by another positive action, but also cases in which we had been satisfied to see mere cessation of action or paralysis by defect. The familiar instance of cardiac inhibitory nerves has led us to look for and find inhibitory nerve action wherever a tissue becomes less active, and in the case of every cessation of action to see not merely a fall of motor action but a rise of anti-motor action. The need for some rational theory of inhibitory action in the well-known case of the cardiac vagus, in the hardly less well-known phenomena of vaso-dilatation, in the whole range of nerve-centre phenomena, has led to doctrinal conceptions apparently most disconnected from an experimental base of departure, yet most provocative of experiments made for the definite purpose of providing such experimental base. The clear case of motor and anti-motor cardiac and vascular nerves has invited us to admit as a probable generalisation that all tissues are controlled by excitatory and by inhibitory nerves. And explicitly or implicitly this generalisation has been operative in the most

apparently disconnected provinces of physiological research and speculation. It has expressed itself most clearly in connection with optical phenomena, with cardiac and vascular phenomena, with the pupil, with glands, and finally with voluntary muscle.

It is hardly possible within the limits of a short article to do more than indicate by a few allusions and headings the present drift of experiments that may fitly be grouped together as illustrating inhibitory phenomena, and supporting more or less cogently the group of speculations that enter into the modern doctrine of inhibition.

With regard to the inhibitory action of the cardiac vagus and the similar less clear but more general case of vaso-dilatator nerves, we are still to-day, as was the case thirty years ago, in presence of two theories, neither of which can be admitted to have finally established itself in undisputed possession. On the older theory an inhibitory nerve (vagus, chorda tympani) takes effect by acting on peripheral nerve-cells, organs of intermediation between nerve-fibres and muscular fibres; on the newer theory they depress activity by promoting the constructive or anabolic phase of nutrition. There is but little positive evidence in support of this second theory; the reversed electrical variation in cardiac muscle due to excitation of the vagus nerve may indeed be due to a reversed trophic movement within the muscle, yet can hardly be admitted as cogent evidence in that respect; we know that the nerve has an anti-tonic, anti-motor effect, and that the variation with such anti-motor effect should be the reverse of that witnessed with a motor effect, need not excite our surprise. Nor have attempts to detect a reversed thermic effect with vagus action led to any more significant results. On the other hand—and this is a consideration that strangely enough seems to have been wholly overlooked—the histological generalisation, confirmed especially by Gaskell's labours, is precisely most in harmony with the older view, and in the scale therefore opposite to that of the newer view; if the old distinction, made especially with reference to vascular nerves, between the cerebral or medullated nerve (vagus and chorda tympani)

and the sympathetic or non-medullated nerve (vaso-constrictors and accelerantes cordis) be admitted, if, further, we admit as proved that the former, which are anti-motor in action, are medullated down to their distribution in a distal series of ganglion cells, while the latter, which are motor in action, are non-medullated in nerve-trunks, having lost their sheath in a proximal series of ganglion cells, it seems a shorter step to admit as probable that an inhibitory nerve-fibre is anti-motor to cardiac and to vascular muscle by virtue of an interference action consummating itself in a distal ganglion cell, than to refer cardiac rest and vascular relaxation to a direct anabolic effect of nerve upon muscle.

In France a somewhat similar question, though differently formulated, has long since been raised.

Bernard never abandoned his first idea concerning the action of the sympathetic, to the effect that it had an inhibitory action upon the tissues, arresting their function, extinguishing, so to speak, or, rather, damping, their combustion, that it was a frigorific nerve. Until the end of his life he maintained that the rise and fall of temperature in the rabbit's ear after section and excitation of the cervical sympathetic were *not* vascular effects, but the consequence of the suppression and exaggeration respectively of a "frigorific" action of the sympathetic. He thus anticipated, and upon experimentally very impure data, the view which is raising its head at the present day, to the effect that the tissues of the body, especially the muscular tissues, are controlled, as well as excited, by nerves, put to rest by anabolic or inhibitory nerves, put into motion by katabolic or motor nerves. But in this view the sympathetic, regarded as the type of a katabolic nerve in England, is presented to us an anabolic nerve. Morat has re-examined under more thoroughly insulative conditions one of the cases relied upon by Bernard in support of this thesis, *viz.*, the case of the submaxillary gland with its two nerves. Bernard had discovered on this gland the well-known effects, *viz.*, cooling by excitation of the sympathetic, warming by excitation of the chorda, but, refusing to admit with Brown-Séquard and Waller that these were effects of vascular constriction and

dilatation, he inferred that the sympathetic and chorda have direct frigorific and thermogenic actions respectively.

Morat finds that, after elimination of the vascular modifications, excitation of *both* the glandular nerves produces a rise of temperature, a result that is consonant with the fact that both are secreto-motor nerves. Proceeding to look for a frigorific effect of an inhibitory nerve, he examines the effect of vagus excitation on the temperature of the cardiac muscle, and finds, as was to be expected, that depression or arrest of the beats is accompanied by a fall of temperature.

In Germany the search for inhibitory effects has been pursued mainly in consequence of the impulsion of Hering's [1] well-known doctrine of assimilatory and disassimilatory processes, first in the retino-cerebral apparatus, then in all tissues; the search has been directed more especially to the voluntary muscles and nerves of the lower animals and of man himself. Biedermann's experiments on the claw of the crayfish and on veratrinised frog's muscle—Kaiser's glycerine experiment on the frog's sciatic—Wedensky's observations also on the frog's sciatic—the investigations of Fick, of Mosso and of Waller on human nerve and muscle, contain data bearing more or less closely upon the question. It is also touched upon by the experiments *re* dilatation of the pupil, by Heese and by Langley and Anderson, and by an observation of Sherrington's with regard to movement of the eyeballs. We might also have mentioned the observations of Orchansky, but that the question of central inhibitory phenomena is too extensive to be properly included in this brief article, which is intended to cover only the question of peripheral inhibitory phenomena.

Biedermann's observations are now generally known; they need, therefore, merely be attended to as among the first definite data giving body to the floating notion of motor states, antagonised and overcome by anti-motor processes consummated in the muscle itself. The main point

[1] Hering, *Zur Theorie der Vorgänge in der lebendigen Substanz.* Prag., 1888.

of these experiments (which do not broach the question of the existence of specific inhibitory nerves) seems to be that as excitation may replace the quiescent by the active state so also may excitation replace the active by the quiescent state. The same electrical excitation causing contraction of relaxed muscle, brings about the relaxation of contracted muscle (veratrinised). In this case we have to do with direct excitation of muscle. In the recent observation of Kaiser (and also in the older, if less precise, observations of Schiff) we have to do with muscular relaxation by indirect excitation—a muscle put into tonic contraction by chemical excitation of its nerve (by glycerine) is made to relax by tetanising induction shocks also applied to nerve.

These are perhaps the least ambiguous data in the direction of the much sought for proof of the existence of muscular inhibitory nerves; they cannot be regarded as satisfactory, but in comparison with other data to which appeal has been made they are clearness itself. Hering's presentation of anodic depression of nerve excitability as a case of inhibition, Mosso's observations on human muscle, Wedensky's experiments on frog's muscle, have very slight and distant connection with the question, and are at best suggestive of many various possibilities.

To draw the conclusion that there are inhibitory nerves to muscle from the fact that the electrical excitation of nerve may interfere with and diminish voluntary and artificial muscular contractions is a step requiring considerable credulity. The datum is, in fact, even more complicated by possibilities than an analogous datum under more simplified conditions that was brought forward by Schiff[1] forty years ago, and rejected by him as fallacious evidence of musculo-inhibitory nerves. The experiment is a well-nigh forgotten one, and may therefore fitly be redescribed as "new"—the nerve of an ordinary nerve-muscle preparation is tetanised by induction shocks until the muscle ceases to respond; at this time single induction shocks applied to another part of the nerve at intervals sufficiently long to allow of recovery

[1] Schiff, *Physiologie des Menschen*, p. 188. Lahr, 1858.

coming into effect, will cause single muscular twitches, and if during a rhythmic series of such twitches the original tetanising current is remade, the twitches are temporarily inhibited just as if the twitching muscle were a contracting ventricle and the sciatic nerve its inhibitory nerve. The experimental fact is clear and elegant, but does not bear the conclusion that would no doubt be placed upon it by special seekers for musculo-inhibitory nerves. Moreover, it has not been cleared of a possible fallacy that was found to be subversive of the somewhat similar experiments of Valentin and of Grunhagen.

If the idea of inhibition and of inhibitory nerves is not to become entirely dissipated, if we are to admit under that rubric the mere passive cessation of action as well as the active arrest of action, then all nerves are inhibitory, all paralysis is inhibition. And to any one convinced of the existence of efferent inhibitory nerves to skeletal as well as to vascular muscle it is no drawback that we do not know whether the cardiac vagus acts directly on the muscle or through the intermediation of ganglion cells, that we do know that all inhibitory phenomena effected through afferent fibres have their seat of consummation in nerve-centres, that the experimental demonstration of musculo-inhibitory nerves is most inconclusive of their existence. And it is possible to go further in the construction of suppositions, to suppose that not only muscle but all living tissues are under the control of direct inhibitory as well as of motor nerves, that inhibitory nerves are inhibitory because anabolic, motor nerves motor because katabolic. But the superstructure in its present state needs to be buttressed and underpinned by more cogent experimental facts than any that have recently been employed for the purpose. The case for the inhibitory nerves of skeletal muscle is unproven.

## BIBLIOGRAPHY.

BIEDERMANN. Ueber Hemmungserscheinungen bei electrischer Reizung quergestreifter Muskeln. *Wiener Sitzungsberichte*, 1885 ; also in *Pflüger's Arch.*, vol. xlvii., p. 243, 1890.

BIEDERMANN. Ueber die Innervation der Krebssheere. *Wiener Sitzungsberichte*, 1887.

FICK. Myographische Versuche am lebenden Menschen. *Pflüger's Arch.*, xli., p. 176, 1887.

GROVES. On the Chemical Stimulation of Nerves. *Journal of Physiology*, xiv., p. 221, 1890.

KAISER. Hummungserscheinung in Nervo-Muskel Präparat. *Zschr. f. Biologie*, p. 417, 1892.

MOSSO. Ueber die Gesetze der Ermüdung. *Du Bois Reymond's Arch.*, p. 89, 1890.

WALLER. On the Inhibition of Voluntary and of Electrically Excited Muscular Contraction. *Brain*, p. 35, 1892.

WEDENSKY. De l'Action Excitatrice et Inhibitoire du Courant Electrique sur l'Appareil Musculaire. *Archives de Physiologie*, p. 687, 1891.

WEDENSKY. Des Relations entre les Processus Rhythmiques et l'Activité Fonctionelle de l'Appareil Musculaire Excité. *Archives de Physiologie*, p. 50, 1892.

LANGLEY and ANDERSON. *Journal of Physiology*, 1892.

SHERRINGTON. *Proc. Roy. Soc.*, 1893.

PIOTROWSKI. *Journal of Physiology*, 1893.

MORAT. L'Inhibition dans ses Rapports avec la Température des Organes. *Archives de Physiologie*, p. 285, 1893.

MORAT. Ya-t-il des Nerfs Frigorifiques? *Archives de Physiologie*, p. 518, 1893.

MORAT. Nerfs et Centres Inhibiteurs. *Archives de Physiologie*, p. 7, 1894.

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# THE NEW THEORY OF SOLUTIONS.

(*Continued from vol. i., p.* 419.)

## FREEZING-POINT.

SINCE solid substance and liquid substance are in equilibrium at the freezing-point, in order that this state of equilibrium may remain undisturbed, the vapour-pressure of the solid must be equal to that of the liquid.

Now, when a solution freezes, experiment indicates that, in general, the solvent alone solidifies. The fact that drinkable water is produced by melting sea-ice supports this conclusion, and evidence of the same nature is afforded by the results of Fritzsche, who on freezing aqueous solutions of coloured substances obtained colourless ice, and by the striking observation made by Rudorff, who found that although solid magnesium platinocyanide had an intensely deep-red colour, yet the ice which separated from its aqueous solutions was colourless.

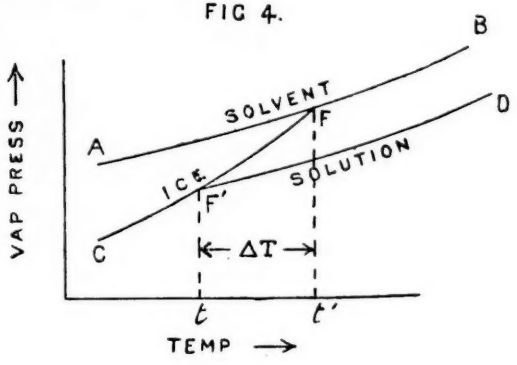
It may therefore be assumed that at the freezing-point of a solution the solid solvent and the solution are in equilibrium, and the freezing-point may be defined as the temperature at which the solution has the same vapour-pressure as the solid solvent.

It can be shown thermodynamically (and experiment justifies the conclusion) that at any temperature below the freezing-point the vapour-pressure of the solid solvent must be lower than that of the supercooled liquid solvent. In fig. 4, CF and AB may thus be taken to represent the vapour-pressure curves of the solid and liquid solvents respectively, and the temperature $t'$, corresponding with the point F at which the curves cut, will be the freezing-point of the solvent. It has been already seen that the vapour-pressure of a solution is lower than that of the pure solvent at the same temperature; DF′ may therefore be taken as

the vapour-pressure curve of the solution, and F′ will correspond to a temperature $t$ which is the freezing-point of the solution, for at F′ the vapour-pressures of solution and solid solvent are the same. It is evident from the diagram that $t$ is less than $t'$; consequently it follows from the fact that the vapour-pressure of a solvent is diminished by the presence of a dissolved substance that the freezing-point is also diminished. The lowering of the freezing-point, $t'-t$ or $\Delta T$, has been found to obey the following laws.

*Influence of concentration.*—The freezing-points of indifferent solutions have only been investigated within comparatively recent times, although more than one hundred years ago James Blagden communicated to the Royal

FIG 4.




Society a series of observations on the freezing-points of aqueous solutions of simple and mixed salts, and announced the law, to which, however, there were exceptions, that the lowering of the freezing-point of the solvent was proportional to the amount of dissolved substance present in the solution. In 1882 Raoult began to employ solvents other than water. For solutions containing not more than 1 gram-molecule of substance in 1000 gr. of solvent, he found *Blagden's law* to be approximately true. Subsequent investigation by Raoult himself, and by other observers, in particular the extensive measurements by Beckmann and Eykman, have proved that, in general, even in dilute solutions, Blagden's law is not strictly obeyed. If, as before,

$g$ be the number of grams of substance present in 100 gr. of solvent, the value of $\Delta T/g$ either slowly increases or slowly diminishes as $g$ increases—the nature of the alteration being of the same order as that discussed in connection with the rise in the boiling-point.

*Influence of the chemical nature of the dissolved substance.*—The most important result announced by Raoult in his first paper was that, for solutions in the same solvent, the *molecular lowering* of the freezing-point is the same. If M′ be the molecular weight of the dissolved substance, $M'\Delta T/g$ is a constant, say F, which depends only on the nature of the solvent. This significant conclusion, published it has to be remembered in 1882, must be regarded as the first broad generalisation arrived at in connection with the stoichiometry of solutions. It gave the clue to the mode of treatment which has been applied with signal success in the case of other properties, as it showed that the solutions which could be most profitably investigated were those containing molecular quantities of dissolved material.

Since $\Delta T/g$ varies slightly with the value of $g$, the same must, of course, be true for the molecular lowering. Raoult has not particularly concerned himself with tracing this variation. It is illustrated in the following tables, wherein the observations for water are due to Arrhenius, and for acetic acid to Beckmann.

SOLUTIONS IN WATER.

| Alcohol M′=46. | | | Ether M′=74. | | |
|---|---|---|---|---|---|
| $g$. | $\Delta T$. | $M'\Delta T/g$. | $g$. | $\Delta T$. | $M'\Delta T/g$. |
| ·575 | ·229 | 18·3 | ·87 | ·22 | 18·7 |
| 1·44 | ·591 | 18·9 | 1·74 | ·42 | 17·9 |
| 2·85 | 1·183 | 19·1 | 2·87 | ·73 | 18·8 |
| 5·70 | 2·456 | 19·8 | 5·74 | 1·51 | 19·5 |

SOLUTIONS IN ACETIC ACID.

| Acetone M′=58. | | | Ethyl Benzoate M′=150. | | |
|---|---|---|---|---|---|
| *g.* | Δ*T.* | M′Δ*T*/*g.* | *g.* | Δ*T.* | M′Δ*T*/*g.* |
| ·502 | ·340 | 39·2 | ·878 | ·230 | 39·2 |
| 4·402 | 2·835 | 37·3 | 5·615 | 1·360 | 36·3 |
| 9·202 | 5·785 | 36·4 | 14·08 | 3·125 | 33·2 |
| 15·91 | 9·740 | 35·5 | 25·53 | 5·180 | 30·4 |

For the solutions given, the value of the molecular rise steadily alters as $g$ increases. In the most dilute solutions, however, the values for different substances dissolved in the same solvent are practically the same.

*Influence of the chemical nature of the solvent.*—In 1882, Raoult concluded that F, the molecular lowering, is proportional to M, the molecular weight of the solvent. The data given by him in 1884 to support this statement are contained in the following table, where F is, for each solvent, the mean value obtained by the use of different dissolved substances.

| Solvent. | M. | F. | F/M. |
|---|---|---|---|
| Water . . . . | 18 | 47 | 4 × ·65 |
| Formic Acid . . . | 46 | 29 | ·63 |
| Acetic Acid . . . | 60 | 39 | ·65 |
| Benzene . . . . | 78 | 50 | ·64 |
| Nitrobenzene . . . | 123 | 73 | ·59 |
| Ethylene dibromide . . | 188 | 119 | ·63 |

The values of F/M do not differ widely from 0·63, and Raoult therefore stated the rule that "when one molecule of a substance is dissolved in one hundred molecules of any solvent, the freezing-point of the latter is lowered by 0·63°". In order to make water harmonise with this rule, the above table shows that its molecular weight has to be taken as 4 × 18, the molecular formula of liquid water being supposed to be $4H_2O$. The value of F for water had been derived

from the study of salt-solutions. The evidence given by them was, however, anything but satisfactory; indeed, it had previously led Raoult to assume $3H_2O$ as the formula of liquid water. Eventually he concluded that the constitution of saline solutions was exceptional, and he adopted 20·3, the value of F given by solutions of indifferent organic substances, as the true value of the molecular lowering. The molecular formula of water had now to be assumed to be $2H_2O$ in order to get a value of F/M agreeing with the rule. The assumption that the molecular complexity of a solvent exercises a definite effect upon the freezing-point of its solutions, is open to the objection that other correlated properties give no indication of being influenced in a similar way. Moreover, any independent testimony which may be taken to prove that the molecule of liquid water is complex, also points to the conclusion that the same is true for formic acid and acetic acid. Hence the molecular lowerings of these solvents as well as that of water should be exceptional if the freezing-point is affected by molecular complexity. The preceding table shows, however, that the acids exhibit no peculiarity. For these and other reasons there is little question that Raoult's explanation of the behaviour of water is incorrect; water is therefore a marked exception to his rule, and in the light of more recent work it is almost certain that the rule is erroneous. What appears to be the correct value of the molecular lowering was deduced thermodynamically by van't Hoff in 1886. He showed that F is not proportional to the molecular weight of the solvent, but is given by the expression $F = 0.02T^2/W$, where T is the freezing-point of the solvent on the absolute scale, and W is its heat of fusion in gram-calories.

Although the observations of Fabinyi (1889) on solutions in naphthalene and thymol support Raoult's empirical rule, the work of Hentschel (1888), and in particular that of Eykman (1888-89), who has carried out a careful investigation of the question, have decided in favour of van't Hoff's theoretical value of the molecular lowering. The data which substantiate this conclusion are collected in the fol-

lowing table. In the second column are given the values, at extreme dilution, of the molecular lowering obtained from observations on the freezing-point of dilute solutions, made, for the most part, by Raoult, Beckmann, and Eykman. In the third column are given the values of the molecular lowering calculated from measurements of the freezing-point and heat of fusion of the solvents, made chiefly by Eykman, Berthelot, Pettersson, and Batelli.

| Solvent. | $M'\Delta T/g$. | $\cdot 02T^2/W$. |
|---|---|---|
| Water . . . . | 18·5 | 18·9 |
| Formic Acid . . . | 27·7 | 28·4 |
| Acetic Acid . . . | 39 | 38·8 |
| Nitrogen Peroxide . . | 41 | 37-43 |
| Lauric Acid . . . | 44 | 45·2 |
| Para-toluidine . . . | 52 | 49 |
| Urethane . . . . | 50 | 50 |
| Benzene . . . . | 49 | 51 |
| Naphthalene . . . | 71 | 69·4 |
| Nitrobenzene . . . | 70·7 | 69·5 |
| Phenol . . . . | 74 | 76 |
| Azobenzene . . . | 82 | 83 |
| Diphenyl . . . . | 82 | 84 |
| Thymol . . . . | 83 | 85 |
| Diphenylamine . . . | 88 | 98·6 |
| Naphthylamine . . . | 78 | 102·5 |
| Ethylene Dibromide . . | 118 | 119 |

Unless in the case of diphenylamine and naphthylamine the agreement between the two sets of values leaves little to be desired. The discrepancy exhibited by these two compounds is very probably to be attributed to impurity in the samples used by Batelli for determining the heats of fusion. This assumption is based upon the low melting-points of his samples. Pure naphthylamine melts at 50°, and diphenylamine at 54°, whereas Batelli's preparations melted at 43·4° and 51° respectively.

There is very little doubt, therefore, that the law of the freezing-point of dilute solutions is given by

$$M'\Delta T/g = \cdot 02T^2/W. \quad (1).$$

*Freezing-point and the gaseous laws.*—Relationships between freezing-point and osmotic pressure may readily be established by means of the connections which exist between

each of these properties and vapour-pressure. Since at the freezing-point a solution has the same vapour-pressure as the solid solvent, solutions in the same solvent having the same freezing-point must have the same vapour-pressure. But solutions which at a given temperature have the same vapour-pressure have been shown to have the same osmotic pressure, consequently solutions having the same freezing-point must have the same osmotic pressure. From the fact that Raoult's determinations have shown that solutions having the same freezing-point have the same molecular concentration, we have another mode of proving that Avogadro's hypothesis is applicable to dilute solutions, or that isotonic solutions contain per unit volume the same number of dissolved molecules.

In order to ascertain how freezing-point observations accord with the general equation PV = ·0819 T, a quantitative connection has to be established between the lowering of the vapour-pressure and the lowering of the freezing-point. Such a connection was deduced as early as 1870, by Guldberg, who started with the well-known equations expressing the heats of vaporisation of the solid and the liquid solvents in terms of the pressure, temperature, and volume of the vapour to which each gives rise. Assuming the vapour to obey gaseous laws, Guldberg's relationship may be formulated as

$$\log_e p/p' = MW/2 \times (1/T' - 1/T) \quad (2).$$

Here $p$ is the vapour-pressure of the liquid solvent, and $p'$ that of the solid solvent, and therefore of the solution, at T', the absolute freezing-point of the solution. T is the absolute freezing-point of the pure solvent. W is the difference between the heats of vaporisation of 1 gr. of solid solvent and 1 gr. of liquid solvent, and is thus the heat of fusion of 1 gr. of solid solvent. If we now substitute for $\log_e p/p'$, its value at T' as given by the vapour-pressure equation (6) (vol. i., p. 414), we obtain on writing $\Delta T$ for T-T'

$$P = ·0819\, \rho W \Delta T/2T^* \quad (3).$$

* In this equation W/2T is assumed to be the same at the freezing-points of the solvent and the solution. Arrhenius has shown that if the

The experimental work on the freezing-point has shown that $M'\Delta T/g = \cdot 02T^2/W$, consequently

$$P = \cdot 0819\ \rho g T/100M' \quad (4).$$

Since $g$ grams of dissolved substance are present in 100 gr. of solvent, the volume, V, of solvent containing M′ grams of dissolved substance will be $100M'/\rho g$ litres. In a dilute solution, since the weight of the dissolved substance is small and the density of the solution differs little from that of the solvent, this may be taken as the volume of the solution. Hence equation (4) reduces to

$$PV = \cdot 0819T.$$

Equation (3) makes it possible to calculate the osmotic pressure from observations on the freezing-point; it indicates that osmotic pressure is independent of the chemical nature of the solvent; and just as in the case of vapour-pressure and boiling-point, the entire discussion demonstrates the validity of the gas-equation as applied to dilute indifferent solutions.

## CONSEQUENCES OF THE VALIDITY OF THE GAS-EQUATION FOR DILUTE SOLUTIONS.

We have now considered the most straightforward evidence which can be adduced to prove that the equation $PV = \cdot 0819T$ is applicable to dilute solutions. As will have been seen, the validity of the application rests solely upon the results of experiment or upon deductions drawn from such results by the aid of well-established thermodynamical principles. It is independent even of any assumption as to whether osmotic pressure is to be ascribed solely to the dissolved substance. Since the data indicate, however, that osmotic pressure is proportional to the concentration of the solution and is not affected by the chemical nature of the solvent, it seems but reasonable to attribute this pressure to the dissolved substance alone, and hence, for the reason already given, it is regarded as the kinetic pressure of the dissolved molecules.

temperature-variation of W be allowed for, the equation still gives good results for the ismotic pressure at T, in the case of aqueous solutions where the lowering of the freezing-point is as high as 10°.

Moreover, since, according to experiment, osmotic pressure is equal to the corresponding gaseous pressure, it is again a plausible assumption that Avogadro's hypothesis may be literally extended to dilute solutions, and, therefore, that the molecular condition of gaseous and dissolved substances is the same. This is in reality the fundamental hypothesis of the new theory : in all dilute solutions to which the gas-equation applies, the dissolved substance is assumed to be present in the condition of simple molecules, and the behaviour of solutions to which the equation is inapplicable finds an explanation in the supposition that in them the molecular state of the dissolved material is exceptional. We are thus led to the conclusion that when the molecules of a substance are widely separated from one another, as in the case of a gas or a dilute solution, the pressure which promotes their diffusion depends solely upon their number and not upon their nature; it is, further, independent not only of the nature, but even of the presence of the solvent.

*Osmotic pressure and diffusion.*—Although this is so, the actual process of diffusion is very different in the case of a gas and a dissolved substance, on account of the enormous frictional forces, due to the presence of the solvent, which oppose the movement of dissolved molecules. On the supposition that osmotic pressure is the cause of diffusion (Nernst, 1888), this frictional force can be calculated. The osmotic pressure-laws give the value of the force promoting diffusion, actual observations give the velocity of diffusion; all the data are thus to hand for evaluating the resistance opposing the movement. In this way it has been found that in order to drive one gram-molecule of sugar through water at 18° with a velocity of 1 cm. per second, a force of no less than $4{\cdot}7 \times 10^9$ kilograms-weight must be employed. That the force should be so large finds an explanation in the extreme smallness of the moving particles—the molecules. Hence, although gaseous and osmotic pressure are equal in magnitude, the equalisation of the pressure of a quantity of gas is almost instantaneous, whereas the equalisation of the concentration and

consequently the osmotic pressure of a solution is a matter of extreme slowness.

*Molecular weights and the properties of solutions.*—Much of the testimony which substantiates the applicability of the gas-equation has been accumulated in the endeavour to utilise the properties of dilute solutions as methods of estimating the molecular weights of soluble substances which cannot be volatilised. It has again to be noted here that these methods are purely empirical. Direct and indirect experiments show that, for substances of known molecular weight, osmotic pressure is equal to the corresponding gaseous pressure. If this rule be extended, and we assert that the osmotic pressure of a soluble non-volatile substance may still be regarded as the pressure which it would exert if it could be vaporised, even in such cases we may estimate vapour density and hence molecular weight. But apart from any correlation of the other properties of solutions with osmotic pressure, it would be rational to employ observations on solutions to fix doubtful or unknown molecular weights. Oft-repeated experiment has proved that in the case of substances of known molecular weight, solutions of the same molecular concentration have the same vapour-pressure, boiling-point, and freezing-point; it is therefore only necessary to extend these results to solutions in general, in order to obtain the molecular weight of any non-volatile substance which is soluble in a suitable solvent. Although the use of these methods may thus be justified apart from theoretical considerations, it was not until van't Hoff's theory had been published that their value became widely recognised. Raoult's first series of observations on the freezing-points of indifferent solutions appeared in 1882. In 1884 he generalised his results and laid especial stress on the ease with which the observations lent themselves to the determination of molecular weights. The first attempt to turn the method to practical account was not made, however, till 1886, when Paterno and Nasini estimated the molecular weights of paraldehyde and dicyanamide from the cyroscopic behaviour of their solutions. In 1888 Victor Meyer drew attention to the great

practical importance of the results of Raoult's work, which he regarded as the most important aid furnished to the chemist by physical methods since the time of Dulong and Petit. In Meyer's laboratory Auwers devised a piece of apparatus for conveniently determining the freezing-point and made a series of observations. Other forms of apparatus for use in the laboratory have been described by Hollemann, Hentschel, Arrhenius, Beckmann, Eykman, Fabinyi and Klobukow. Of these, the patterns due to Eykman and Beckmann have found most acceptance; indeed the form devised by the latter, its main feature being a specially constructed thermometer, is now regarded as a necessary part of the equipment of any well-appointed laboratory. For very delicate measurements, Raoult, Pickering, Loomis, H. C. Jones, and Lewis, have also described pieces of apparatus.

Attempts have been made to adapt the various modes of estimating vapour-pressure to the determination of molecular weights. In 1889 Beckmann tried to suitably modify the statical method, but his work, as well as that of Tamman and Loeb, clearly demonstrates the difficulties which stand in the way of its adoption in the laboratory. Methods which consist in estimating the weight of vapour given off from solvent and solution have been used by Tamman, by Walker at Ostwald's suggestion, by Will and Bredig, and by Beckmann. They can only be satisfactorily used with solutions of medium concentration. Ostwald has proposed the employment of a hygrometer, and Charpy has made some measurements with this instrument. By far the most convenient apparatus is based upon the dynamical or boiling-point method of estimating vapour-pressure. Many of Raoult's results were taken in this way, and in 1889 and 1891 Beckmann described two handy pieces of apparatus which admit of the determination of molecular weights from the boiling-point of solutions with almost as much ease and precision as from the freezing-point. Wylie and Sakurai have also described similar methods.

In what has been said regarding the boiling-point of solutions it has been presupposed that, as compared with

the solvent, the dissolved substance is practically non-volatile. Planck (1888) has theoretically investigated the more general case of solutions of volatile substances, and Winkelmann (1890) has experimentally verified Planck's conclusions. Nernst has more recently taken up this question, and shown that as a consequence of the new theory it is possible to obtain evidence regarding the molecular weight of a volatile substance from the boiling-point of its solutions. Because, if the molecular weight of the dissolved substance be the same in the solution as in the state of vapour, the partial pressure of its vapour should be proportional to the strength of the solution, and the rise or fall which it produces in the boiling-point of the solvent should be proportional to the concentration ; whereas, if the molecular weights differ in the two states, there should be no proportionality.

Observations on osmotic pressure may also be employed to ascertain molecular weights, although the methods are in no case so convenient as those just alluded to. The most suitable of the indirect methods are based upon the use of vegetable cells, or red blood corpuscles (see vol. i., pp. 19-22). By the former, in 1888, De Vries concluded that of the formulæ which had been proposed for raffinose, the $C_{18}$-formula was correct. This conclusion has since been confirmed by purely chemical evidence. The plasmolytic methods are of interest as they show how the microscope may be employed to determine molecular weights. They can only be used, however, with solutions in which protoplasm can live.

In 1889, Ladenburg announced that he was perfecting a method of estimating molecular weights from direct observations on osmotic pressure, but as yet no further details have been published.

*The general kinetic theory of solutions.*—Not only has the new theory of solutions proved itself a powerful stimulus to the development of such a practical subject as the determination of molecular weights, but it has also given rise to several important speculations regarding the general kinetic theory of solutions. These have, in the main, confirmed the hypothesis of the new theory.

On the assumption that dissolved substances exist as simple molecules, and that the energy of translation of the molecules is the same as in the case of a gas at the same temperature, Boltzmann, Lorentz, and Riecke (1890-91), each starting from a different point of view, have found, by means of purely mechanical principles, that the pressure of dissolved molecules should be equal to the corresponding gaseous pressure. From thermodynamical considerations, Planck and Duhem arrive at results which, in the main, support the same conclusion, and van der Waals' complex equation for a mixture of two substances, in the case of a dilute solution, simplifies down to the gas-equation.

*Dissolution and evaporation.*—As consequences of the new theory of solutions may be classed the views propounded by Nernst regarding the nature of the process of dissolution, and the results which have been derived therefrom. The analogy between dissolution and evaporation was pointed out by Dossios as long ago as 1867, and from time to time it has been employed by writers on solution. The conception of osmotic pressure for the first time rendered this analogy definite. According to Nernst (1889), we may imagine that when a substance is in contact with a solvent an expansive force is at work whereby molecules pass into the solvent until the pressure they exert—the osmotic pressure—reaches a definite value, which we may term the *solution-pressure*. The process is thus taken to be strictly comparable with that whereby a solid or a liquid evaporates into a gas until its partial pressure reaches a definite limiting value, the vapour-pressure.

*Diminution of the solubility.*—Of the various consequences which flow from this conception of the nature of dissolution, the effect of a dissolved substance on the solubility of a liquid may be discussed here. If the analogy between dissolution and evaporation be valid, since the vapour-pressure of a solvent is diminished by the presence of a non-volatile dissolved substance, the solution-pressure and hence the solubility of a liquid A in a solvent B should be diminished by the presence in A of a substance insoluble

in B. Moreover, the diminution in solubility should follow the same law as the diminution in vapour-pressure. Thus, to take an example, using water as solvent, if L be solubility of ether, and L′ the solubility of ether containing a dissolved substance insoluble in water, then in all the equations we have discussed dealing with the vapour-pressures of solutions, we may substitute (L-L′)/L′ for $(p\text{-}p')/p'$, and hence from (3) vol. i., p. 411, we may obtain

$$(L\text{-}L')/L' = n/N \quad (5).$$

Consequently, the relative diminution in the solubility of the ether should be the same as the ratio of the number of molecules of dissolved substance to the number of molecules of ether present in the solution. In 1890 Nernst gave a thermodynamical proof of the above equation; experiments to test its validity, although easy to perform, are not very numerous, however, on account of the difficulty of obtaining suitable solvents. The solvent B must be practically insoluble in the liquid A. In his experiments Nernst used water as solvent and found the solubility of valeric acid, ether, and ethyl acetate, containing different dissolved substances. So far as these experiments go they accord with equation (5).

We have here, therefore, another indirect mode of proving that the gas-equation is applicable to dilute solutions and another mode of estimating molecular weights. Quite recently (1894) Küster has attempted to make such measurements on solubility the basis of a laboratory method of determining molecular weights.

*Osmotic pressure and the partition-coefficient.*—The analogy between dissolution and evaporation leads to another and indeed the most direct indication that osmotic pressure is independent of the nature of the solvent. Berthelot and Jungfleisch found in 1872 that the partition-coefficient of a substance between two mutually insoluble solvents was independent of the amount of dissolved substance. Thus at 15°, if iodine be shaken with water and carbon bisulphide, the ratio of the concentration of the iodine in the bisulphide, to that in the water, is 410, no matter how much iodine be employed. This result leads

to the conclusion that if iodine were gasified it would obey Henry's law, its solubility in either solvent being proportional to the gaseous pressure. Now van't Hoff has shown that for a substance obeying Henry's law the osmotic pressure is equal to the corresponding gaseous pressure, hence it follows from the constancy of the partition-coefficient that if one gram of iodine be dissolved in the same volume of water or carbon bisulphide, the osmotic pressure will be the same in each case (Nernst, 1891).

*Correlation of the different modes of proving the validity of the gas-equation.*—We have now dealt in detail with five different modes of determining molecular weights and of proving that the gas-equation applies to dilute solutions. Why each of these methods leads to the same result depends upon the fact already stated, that the properties to which they refer are correlated properties. A simple mode of showing the reason for the coincidence in the conclusions to which they lead, and of indicating the nature of their correlation, has been given by Nernst, who has called attention to the fact that they are all concerned with the separation of solvent and dissolved substance. In the case of osmotic pressure this separation is effected by directly forcing the solvent through a semi-permeable membrane, in the case of the freezing-point the solvent is made to crystallise out, in the case of vapour-pressure and boiling-point it is made to volatilise, and finally in the solubility-method, a solvent A is made to separate from a liquid B by dissolving in B a substance insoluble in A. Each method furnishes a means of ascertaining the work required to bring about this separation, and hence each is but a different mode of attacking the same problem.

In the above methods the solvent is made to separate from the solution. It is of course possible to devise parallel methods in which the dissolved substance is made to separate—by crystallisation, evaporation, etc.—and already van't Hoff, Nernst, Deventer and Stadt, and others, have laid the foundation of the development of this side of the question.

J. W. Rodger.

(*To be continued.*)

# RECENT RESEARCHES IN THERMAL METAMORPHISM.

## PART I.

FEW questions, if any, on the physical side of geology have attracted more attention than those connected with the metamorphism of rock-masses; and, in view of the vast areas occupied in many parts of the world by rocks which either are, or have been considered, metamorphic rocks, it cannot be said that the importance of the subject has been over-rated. Most of our geological text-books divide metamorphism into "local" or "contact," observed in the vicinity of intruded igneous rocks, and "regional" or "normal," more widely distributed and ascribed rather vaguely to various causes. When we come to discuss the probable conditions under which extensive transformations of rock-masses have been effected, this division does not seem to be a philosophical one. The two causes to which geologists have been led in seeking the explanation of the most striking phenomena of metamorphism are high temperature and mechanical force, and the true distinction therefore seems to be between *thermal* and *dynamic* metamorphism. As regards structural and, to a less extent, mineralogical changes, the two sets of phenomena are found to be in great part distinct: there must arise, however, cases in which the discrimination presents difficulties, and cases in which the effects of the two causes have been impressed simultaneously or successively upon the rocks of the same area.

"Contact-metamorphism," due to the heat of an intruded igneous magma, must stand as the typical case of thermal metamorphism, in the sense of offering the simplest and least ambiguous examples for investigation; but it is not the only case. In the rise of the isogeotherms, as pictured by Babbage, Mellard, Reade and others, extensive tracts of rocks once cool may be directly invaded by the

internal heat of the earth, and thermal metamorphism thus produced on a regional scale. Further, the mechanical generation of heat in connection with crust-movements must give rise to phenomena of thermal metamorphism, which we may expect to find often complicated by purely dynamic effects.

In this country a considerable amount of study has been devoted to thermal metamorphism in the last twenty years, the lead being taken by Allport in Cornwall, and Clifton Ward in the Lake District. Among more recent contributions may be mentioned those of Miss Gardiner (1) on the New Galloway district, Barrow (2) on the South-eastern Highlands of Scotland, and Harker and Marr (3) on the rocks surrounding the Shap granite. On the continent Rosenbusch has rendered classic the district of the Steiger Schiefer in the Vosges, Lossen the Harz Mountains, Brögger and afterwards Lang the neighbourhood of Christiania, and Barrois the west of Brittany. As preliminary to some more general remarks on thermal metamorphism, I select some recent researches in Saxony, which illustrate characteristic phenomena in rocks belonging to various lithological types, and are worthy of being better known by English geologists.

The metamorphism produced by the intrusion of the great mass of the Meissen syenite was described by the officers of the Saxon Geological Survey a few years ago. Some of the features, as noticed by Sauer (4) in the memoir accompanying sheet 48 of the map, are well worthy of notice. The aureole of metamorphism has a breadth of about two kilometers, or in places where the syenite underlies the strata at a low angle as much as four kilometers. The rocks affected belong to the Ordovician and Silurian formations. They are for the most part ordinary clay-slates with disseminated carbonaceous matter; but these sometimes pass, on the one hand, into fine-grained siliceous slates (Kieselschiefer and Adinolschiefer), and, on the other hand, into bands of greywacke and beds of quartzite. There are also basic volcanic rocks ("diabase-tuffs" and "diabases"), and, associated with these, beds of pure limestone.

The clay-slates and cleaved greywackes are converted in the neighbourhood of the intrusion into rocks composed chiefly of andalusite, biotite, and quartz, with or without a schistose character, or into sillimanite-bearing quartz-biotite-schists. The andalusite, in crystals up to 1 cm. long, is very abundant, and, as usual, crowded with inclusions of other minerals, such as quartz, biotite, and magnetite. Muscovite and felspar have also been formed, and of these too the larger crystals are full of inclusions. The sillimanite occurs in the usual crowded aggregates of needles, but it is curious that these occur even more in the biotite-flakes than in the quartz. The minute rutile-needles, which are abundant in the original clay-slates, have disappeared in the metamorphism, the titanic acid being taken up by the new-formed biotite.

Outside the zone of most highly altered rocks is a zone of "knotted" or "spotted" mica-schists (Knotenglimmerschiefer), and a point of special interest is the discovery that in a large part of these rocks the "knots" are really crystals of cordierite. In the siliceous and alum-slates, which in their original state contained a quantity of free hydrous silicate of alumina, the alteration extends to a greater distance from the syenite, the characteristic product being chiastolite in crystals 1 cm. long.

The adinole-like rocks are metamorphosed into quartzite-schists, and the original quartzites appear to have been recrystallised near the intrusion. The quartz in the metamorphosed rocks is free from fluid-pores.

The basic tuffs have given rise to hornblende-schists and especially anthophyllite-schists, the augite and its decomposition-products being converted into hornblende or actinolite or to a great extent into the rhombic amphibole anthophyllite, while the felspars are recrystallised. The associated limestones, originally fine-textured to compact, become usually rather coarse-grained marbles; but the thin-bedded alternations of limestone with tuff give rise in the immediate neighbourhood of the syenite to more complex mineral-aggregates similar to those well known at Monzoni in the Tyrol. The minerals produced include garnet, ido-

crase, epidote, zoisite, augite (malacolite), hornblende, biotite, anthophyllite, and cordierite.

Farther south, on sheet 64 of the map, older rocks, including phyllites, mica-schists and gneisses, come within the influence of the syenite. The phenomena have been briefly described by Dalmer (5). The phyllites are converted into "Fruchtschiefer" like those known in the Erzgebirge. The little concretionary patches consist of a dark green substance containing a high percentage of alumina and ferrous oxide and ten per cent. of water. The chief effect of metamorphism in the mica-schists is the production of andalusite, while the gneisses show no appreciable change.

The above areas lie to the west and north-west of Dresden. The district to the south-east of that city, still on the left bank of the Elbe, exhibits features of at least equal interest, which have recently been described in several memoirs by Beck (6). The chief intrusive masses with which the metamorphism is connected are the Lausitz granite and a syenite similar to those of Meissen and Dresden. The rocks affected range from pre-Cambrian to Devonian, and belong to very various petrographical types.

The pre-Cambrian phyllites show the following successive stages of alteration, as they approach the granite: (i.) "Fruchtschiefer" with unaltered matrix, (ii.) "Fruchtschiefer" with recrystallised matrix, (iii.) schistose micaceous rocks, and (iv.) andalusite-mica rocks. The changes involved are the gradual disappearance of the chlorite, with concurrent development of brown mica and andalusite, the recrystallisation of the quartz with increasing coarseness of grain, and the production of what the author styles typical "contact-structure," *i.e.*, an interlocking of the irregularly polygonal grains of such newly-formed minerals as quartz and felspar. Precisely similar phenomena were previously described by Dalmer in the Western Erzgebirge. Some chlorite-gneisses associated with the phyllites are converted into biotite-gneisses, while certain felspathic quartzites also show a production of biotite and a recrystallisation of quartz and felspar in a clear mosaic ("contact-structure").

The Ordovician and Silurian rocks of the district have a great variety of characters. The clay-slates pass through the stages of "Knotenschiefer," "Knotenglimmerschiefer," and "Hornfels" with the production of biotite, quartz, muscovite, etc., but cordierite is uniformly produced instead of andalusite. Pyrite is replaced by pyrrhotite. The rutile-microlites of the original slates are recrystallised as larger grains of rutile or locally converted into little crystals of brookite. The siliceous rocks ("Kieselschiefer," etc.), some of which seem to be radiolarian cherts, are converted into quartzites; graphite, up to as much as two per cent., representing the original carbonaceous matter. Other minerals produced are biotite, chiastolite, and pyrrhotite. The greywackes are recrystallised as a mixture of quartz, biotite, muscovite, plagioclase, etc., while their clastic origin is still indicated by angular fragments of quartz which keep their original outline, but are seen to resolve in polarised light into a mosaic of smaller grains.

The calcareous rocks give rise to an important observation which is probably of general application. The pure limestones are simply recrystallised as marble, while the impure ones lose their carbonic acid, and pass into rocks consisting mainly of lime-bearing silicates. The characteristic minerals here are garnet and augite: actinolite, epidote, zoisite, etc., also occur, but wollastonite, idocrase and scapolite are not found. The absence of wollastonite seems rather remarkable, since the limestones analysed are not magnesian. In other places more complex results have been produced by an impregnation of the limestones with ore-material, probably concurrent with the metamorphism.

Certain "diabases" (apparently andesitic lavas) show considerable metamorphism, the most characteristic feature being the amphibolisation or uralitisation of the augite, which process is seen in various stages. Besides the light green hornblende, which is the most prominent constituent of the altered rocks, occur subordinate biotite, unchanged augite, sphene, iron-ores, etc., while the general groundmass of the rock is a mosaic of clear granules of plagioclase. The characteristic pyrrhotite is here wanting. Tuffs asso-

ciated with the lavas show, on the whole, similar changes. Anthophyllite sometimes takes the place of hornblende. There occur also banded schists, in which alternate layers are rich in green hornblende and colourless augite, respectively. The latter mineral is a malacolite variety, and is clearly a metamorphic product.

The metamorphism of the Devonian strata, consisting of greywackes and conglomerates, also presents some points of interest. In particular, the metamorphosed pebbles still retain their outlines in their metamorphosed matrix.

These observations, made in the neighbourhood of the large intrusive masses of Saxony, have been cited because they raise several points of general interest. Without mentioning in detail the results obtained in numerous other areas of metamorphism, we may now go on to notice these and some other points in a more general manner. Since the phenomena of metamorphism depend in the first place upon the nature of the rocks metamorphosed, the remarks to be made will be most conveniently grouped in that way.

Beginning with the *argillaceous* sediments, which have, perhaps, received more attention than other types of rocks in connection with thermal metamorphism, we may first note as highly characteristic the production in the altered strata of anhydrous aluminous silicates, including under that name the simple silicates of alumina and some more complex minerals containing a large proportion of that base. Since these aluminous silicates are, with unimportant exceptions, absent from all rocks known to have been formed from igneous fusion, they may perhaps afford a useful criterion in some cases. Indeed it would scarcely be too much to say that, when a gneissic or other rock of problematical origin is found to contain abundant andalusite or some allied mineral, there is a considerable presumption in favour of regarding the rock as a metamorphosed argillaceous sediment. In the composition of a normal igneous rock there is a sufficiency of alkalies, lime, and other bases, and of silica, to enable all the alumina to be built up into felspars, pyroxenes, and other common "rock-forming"

minerals. But in the processes by which such a rock furnishes the material for sediments, chemical as well as mechanical degradation plays a part; and, in particular, the soluble become separated from the insoluble products of alteration; the alumina, in whatever combination, remaining among the latter, and so becoming relatively more abundant. Recrystallisation of the derived sediment by thermal metamorphism must therefore give rise to new combinations, including some mineral rich in alumina.

Andalusite and its variety chiastolite have long been known as characteristic metamorphic products in altered shales and slates; but it has only recently been recognised that cordierite plays in some districts a similar part. The widespread occurrence of this mineral as a "contact" product was first made known from the Saxon area described above, but it is found under the same conditions in other parts of the world, and it is possible that further examination may discover it in some districts where it has been overlooked.

In Japan, cordierite is known in several localities. It was noted by Hussak in 1883 from the Asama-yama district, but recently a more remarkable occurrence has been described by Kikuchi (7) from the Waterase-gawa. The mineral occurs there as a "contact-mineral" in dark Palæozoic slates, and is remarkable not only for the large size and frequent freshness of its crystals, but also for their peculiar structure. Besides the usual polysynthetic twinning, giving a hexagonal cross-section with division into six sectors, each crystal shows an inner and an outer portion. The division between the two portions shows as a hexagon in transverse sections and as two diagonal lines in longitudinal sections. These and the junctions of the several twinned individuals are marked by accumulations of inclusions, mostly of carbonaceous matter. The mineral thus presents a distinct variety of cordierite corresponding with the chiastolite variety of andalusite.

Some approach to this structure is seen in cordierite in the metamorphosed Skiddaw Slates of the Caldew Valley in Cumberland (8), but the crystal-grains are there much

smaller, less perfect, and less fresh than in the Japanese occurrence. Hutchings (9) has recently identified as cordierite the essential mineral of the "spots" in the metamorphosed Coniston Flags near the Shap granite, and remarks its close resemblance to the occurrence noted by Beck in the Elbe Valley in Saxony. The grains are small, rounded, and full of inclusions, and do not show the polysynthetic twinning so characteristic of better developed crystals of cordierite. In view of this discovery and that near the Skiddaw granite, it seems probable that cordierite may be found in other areas of "spotted" slates in this country.

The curious spotted or nodular rocks (Fleckschiefer, Knotenschiefer, etc.), which are so common in districts of metamorphosed slates, still present some difficult problems. In one type the spots, as described by Rosenbusch and others, are due merely to local aggregation of the carbonaceous or other pigment which was originally disseminated through the general mass. Rocks of this kind are found in the outer border of many areas of thermal metamorphism, and usually show little or no important recrystallisation. Quite distinct from these are spotted rocks showing more advanced alteration, in which the spots are little patches relatively free from the biotite or other conspicuous secondary mineral produced in the metamorphism. Examined by optical tests in thin slices, these spots often show a distinct crystalline reaction, and are found to be really imperfectly formed crystals, often further obscured by numerous foreign inclusions. In some cases the constituent mineral of the spots has been found to be andalusite; in others, as already mentioned, it is cordierite; and it is possible that other aluminous silicates may figure in some other cases. It is to be noticed that in the most advanced stages of metamorphism spotted and nodular structures of all kinds have usually disappeared altogether, and the same is often true of the more marked foliation and parallel-structures frequently observed in the less metamorphosed strata. The rocks at the inner border of an aureole of contact metamorphism (the Hornfels of German writers) commonly show in thin slices a mosaic of irregular polygonal grains

due to complete recrystallisation of the rock-mass: this is what Beck terms "typical contact-structure".

Numerous instances are known in which chiastolite is produced in relatively large crystals in the early stages of metamorphism, but gives place in the more altered rocks to andalusite, usually in smaller and less perfect crystals. Again, sillimanite or fibrolite, dimorphous with andalusite, occurs abundantly in some very highly metamorphosed slates, flags and grits. It is embedded as bundles of parallel or sub-parallel needles in grains and patches of quartz, to which it imparts a peculiar opacity and silky lustre ("quartz sillimanitisé" or Faserkiesel of some continental geologists), or it occurs in similar fashion in the interior of flakes of muscovite or sometimes of biotite. It has been described by Barrois in Brittany, and also occurs in abundance in the highly metamorphosed rocks described by Miss Gardiner (1) near New Galloway and by Barrow in Forfarshire (2). In the latter area occurs still another form of the pure silicate of alumina, *viz.*, disthene or cyanite.

Such facts as these raise an interesting question: Can we to any extent specify the conditions which determine what particular aluminous silicate shall be formed in a given case? The minerals produced during metamorphism must, of course, depend in the first place upon the nature of the rocks affected; but in the group of minerals considered some (chiastolite, andalusite, cyanite, sillimanite) have identically the same chemical composition, and some others do not differ very greatly from one another in this respect. We are therefore led to infer that physical conditions, and especially the temperature attained during the metamorphism, must be a considerable factor in determining the formation of one or other of the allied minerals. Barrow's work in Forfarshire has an important bearing on this question. There can be little doubt that the striking features of that area are due, in the main, to thermal metamorphism on something approaching a regional scale, but the phenomena of extreme metamorphism are localised in connection with certain intrusions of gneiss and pegmatite. In the altered rocks, which have undoubtedly once been

sediments, the author named has mapped three zones of metamorphism, characterised respectively by staurolite, cyanite, and sillimanite. Followed along its strike, a bed which in the outer zone is a staurolite-schist, becomes in the intermediate zone a cyanite-gneiss, and in the inner one a coarse sillimanite-gneiss. These differences seem then to be due to differences of temperature ; and, if it is permissible to press the result to its logical conclusion, the line dividing the cyanite-zone from the sillimanite-zone represents what was an isothermal line during the metamorphism. It is even possible to form some idea of the temperature to which this line corresponds. Vernadsky's experiments have shown that cyanite can be converted into sillimanite by raising it to 1320° to 1380°C. : allowing for the great pressure under which the metamorphism was doubtless effected, we may conclude that the temperature reached at the outer edge of the sillimanite-bearing zone was considerably higher than this figure.

In numerous districts geologists, in studying the "aureole" of metamorphism around a large plutonic mass, have divided it into three or four successive zones or rings, the stages of advancing metamorphism being marked sometimes by the incoming of some special mineral, but also by the appearance and disappearance of spotted, foliated, or other structures in the rocks. The results in different districts do not always bear very close comparison. Such observations as Barrow's, however, would seem to import an element of precision into the subdivision of a metamorphic aureole, and it is therefore very desirable that the interpretation of them should be confirmed by similar study in other regions. Other test-minerals might also be selected: the trimorphous minerals consisting of titanic acid at once suggest themselves. Minute needles of rutile seem to be almost universally present in ordinary clay-slates. In the metamorphism of such rocks the titanic acid is often taken up by new-formed brown mica, or sometimes by micaceous ilmenite or granular sphene ; but in some circumstances the little needles are simply recrystallised as stouter prisms of rutile. Again the rutile-needles may be transformed into

little crystals of anatase, as found by Hutchings in the Coniston Flags near the Shap granite (3), or of brookite, as described by Beck (6), (10) in the slates of the Elbe Valley. These latter, purely paramorphic, changes, however, seem to occur locally and somewhat capriciously, so that it is not yet possible to refer the production of one or other of the three forms of titanic acid solely to the effect of higher or lower temperature of metamorphism. Further study in this line may perhaps lead to some more definite conclusion.

An interesting result of such researches as those of Miss Gardiner and of Barrow in Scotland is the clear evidence that thermal metamorphism of sedimentary strata may give rise to thoroughly typical gneisses, some characterised by such minerals as garnet, sillimanite, etc., but also in many examples rich in felspar. The abundant occurrence of felspars of various kinds in thermally metamorphosed sediments is now established by the observations of many petrologists. The apparent reluctance with which some have admitted it is perhaps partly due to the difficulty of identifying the minerals when they occur in a fine-grained mosaic. Such varieties as orthoclase, albite, and oligoclase naturally occur plentifully in the metamorphism of such slates, flags, and greywackes as had not been greatly impoverished in alkalies in the processes by which they were derived from felspathic crystalline rocks; and in these the aluminous silicates may be only feebly represented. Facts drawn from the study of thermal metamorphism cannot fail to have an important bearing on the problem of the gneisses and other crystalline rocks which constitute the much-debated "Grundgebirge" of large tracts of country in Europe and elsewhere. It is becoming increasingly manifest that under such a name as "gneiss" have been included rocks having quite diverse modes of origin. Some are doubtless igneous rocks, with structures either original or impressed on them by dynamic metamorphism; but others are to be regarded as metamorphosed stratified rocks of various types. It has already been remarked that the occurrence of special characteristic minerals may throw light on the origin of such rocks in some cases. Chemical analyses may

be at least equally significant. On the ground of chemical composition alone, Rosenbusch (11) has claimed as metamorphosed sediments various gneisses in Sweden, in the Black Forest, in the Odenwald, in Bavaria, etc., as well as certain hornblende-schists and allied rocks; while he has shown that other gneisses in Sweden, in Saxony, in the Vosges, etc., give chemical analyses, which affords strong presumption of their true igneous origin. Under the latter head he also places the Saxon granulites, various hälleflintas and eurites from Sweden, and pyroxene-granulites, eclogites, chlorite-schists, and talc-schists from various localities. The day of sweeping theories of the origin of gneissic and foliated crystalline rocks in general is past, and it is very generally admitted that each area must be treated as offering a separate problem in itself. We have yet to learn to what extent the hypothesis of thermally metamorphosed sediments is applicable to large tracts of crystalline rocks, but the present tendency of opinion, while leaving room for the dynamic theories of the school of Heim and Lehmann, still points to a partial vindication of the early Lyellian doctrine of metamorphism.

Passing on to the *arenaceous* rocks, we may remark first that different types which would be roughly grouped under this head give rise by metamorphism to widely different products. In the metamorphism of a pure quartz-sandstone there can, in the nature of the case, be no very sharply defined stages. The rock is not capable of any transformation short of complete recrystallisation, and so it will be practically unaltered except where a certain high temperature has been reached during the metamorphism. Some minor changes should, perhaps, be excepted, such as the expulsion of water from the fluid-pores of the quartz, an effect noted by Sorby at Salisbury Crags, Edinburgh.

The quartzite which results from the complete recrystallisation of a sandstone is, in general, easily distinguished, at least in microscopic preparations, from a quartzite produced by the infiltration of a siliceous cement. In the latter case the difference between the original clastic grains and the new-formed quartz-cement is clearly accentuated, while the

former shows in thin slices a uniform mosaic structure. Local conversion of sandstones into quartzites of this type is frequently seen where the strata abut upon any considerable body of intrusive rock. In many cases the metamorphism is further made evident by the production of special accessory minerals arising from impurities (decomposition-products, etc.) in the original sandstone. Near the Shap granite (3) the grits in the Coniston Flag group are converted into quartzites containing numerous granules of pyroxene, probably formed from kaolin and calcite in the strata metamorphosed. The quartzite of Clova, in Forfarshire (2), contains a curious green mica, and other accessory minerals are found in other examples.

An interesting account has been given by Horne (12) of the changes produced in the radiolarian chert in the Arenig beds of the south of Scotland near the large granite mass of Loch Doon. At about a mile from the contact the chert begins to take on a granulitic structure, which becomes more pronounced and coarser, while brown mica begins to be developed. At half a mile from the granite, where this change is well-marked, the traces of radiolaria can still be detected. Near the contact the chert is completely recrystallised, a curious feature being the numerous perfectly rounded inclusions of biotite contained in the quartz-grains, which otherwise constitute the whole of the metamorphosed rock. The carbonaceous matter, which in the analogous rocks described by Beck gives rise to graphite, is here absent. In the Devonian and Carboniferous "Kieselschiefer," metamorphism by the Brocken granite has apparently expelled the carbonaceous matter almost completely (Lossen, 1888).

More impure gritty rocks give rise by metamorphism to less simple products. Silicates of alumina, garnet, micas, etc., may be extensively produced, and the resemblance to a quartzite is lost. Sillimanite is very plentiful in some highly metamorphosed rocks, such as those of Guéméné in Brittany, described by Barrois (1884). In coarse sediments of composite nature evidence of their clastic origin may be preserved after very considerable modification, as we have

seen in the Saxon greywackes and conglomerates. Recrystallised felspars play a more or less important part in many highly metamorphosed arenaceous strata, which are sometimes typical gneissic rocks of somewhat coarse texture. The Silurian gneisses of the New Galloway area (1) have been in part grits and flags rather than shales.

In his valuable report on the igneous rocks of Arkansas, the late J. F. Williams (13) described some very curious contact-phenomena in the siliceous rocks of Magnet Cove, a district which has long been known to mineralogists as the locality of several interesting mineral species and varieties. The strata in question are the well-known novaculites or whetstones and the sandstones associated with them, and the special minerals developed are ascribed to the invasion of a group of elæolite-syenites and allied igneous rocks. The most interesting mineral is brookite, which occurs in brilliant black crystals coating the faces of certain large crystals of quartz. It is of peculiar habit and characters, and was originally described under the name arkansite. Brookite resulting from the metamorphism of rutile-needles has been noticed elsewhere, but the conditions of its occurrence at Magnet Cove seem to be different. Williams states that the unaltered strata are practically free from titaniferous material, and he supposes the titanic acid which builds the brookite crystals to have been derived from the syenite. Good crystals of rutile have also been formed, besides rutile paramorphic after brookite. Crystals and rosette-like groups of hæmatite, which occur sparingly, are also probably titaniferous. On the question here raised, of an actual transference of material from an invading magma to the adjacent rocks, some remarks will be made later.

Some of the most instructive features of thermal metamorphism are found in connection with *calcareous* strata. Pure limestones and dolomite-rocks, which have been subjected to a sufficiently elevated temperature, are always found to have recrystallised without chemical change. The carbonates are not decomposed by heat alone. The resulting crystalline marbles have commonly lost all trace of

original structures, fossils, etc., and may closely resemble the crystalline limestones produced from similar calcareous sediments by aqueous agency alone. In many cases, however, the crystalline limestones and dolomite-rocks which owe their characters to thermal metamorphism are readily distinguished by the occurrence in them of special accessory minerals arising from non-calcareous impurities in the original strata. The most significant of these special minerals are various silicates rich in lime or sometimes in lime and magnesia. Some of them, such as anorthite and the various augites and hornblendes, are well-known minerals of igneous rocks; others, such as wollastonite, zoisite, idocrase, and lime-garnets, are rare or unknown as constituents of rocks formed from igneous magmas.

In a tolerably pure limestone these accessory metamorphic minerals are formed sporadically or often in nests or streaks marking the places where siliceous or argillaceous impurities were collected in nodules or bands. Two or more minerals are often associated with a definite arrangement. Thus, in certain beds of the Coniston Limestone metamorphosed by the Shap granite (3) occur nests consisting of stellate groups of idocrase crystals surrounded by a shell of felspar, which is again bordered by clusters of pyroxene-granules passing into the matrix of crystalline calcite. Attention to the mode of occurrence of the accessory minerals is sometimes necessary to avoid mistakes as to the origin of a rock. The well-known Tiree limestone is an example. This is a rather finely crystalline marble containing abundant grains of salite with some felspar, sphene and other characteristic metamorphic minerals; but a closer scrutiny makes it clear that these minerals have not been formed in place, but occur here as detrital elements. The structure of the rock and the interesting effects of pressure on it have been described by Bonney (14). The grains of salite, etc., may have been derived from some pre-existing metamorphosed limestone. Sollas and Cole (15) have suggested that they may represent a volcanic sand mingled with what was once a coral sand.

An interesting contribution to thermal metamorphism is given incidentally by Brögger and Bäckström in their memoir on the minerals of the garnet group (16). Under the head of alkali-garnets they place sodalite and its allies, including the natural ultramarine lasurite, the constitution of which is shown to be analogous to that of the garnets proper. The well-known, but hitherto mysterious, lapis lazuli or Lasurstein is found to be a product of thermal metamorphism in a calcareous rock. It consists of lasurite, blue and white haüyne, diopside, often hornblende and a micaceous mineral, and calcite, with pyrites, etc.

Some interesting phenomena of metamorphism in calcareous rocks have been described by J. F. Williams (13) at Magnet Cove in Arkansas, a district already referred to. The crystalline limestone at that locality contains several special minerals referable to thermal metamorphism, the most important being lime-bearing silicates. These include crystals of perofskite or dysanalyte, idocrase, and the lime-magnesia-olivine monticellite, the conditions resembling in some degree those of the classical district of Monzoni in the Tyrol. Other minerals met with are octahedra of magnetite, masses of apatite-needles, and a green biotite.

The occurrence of dipyre in the metamorphosed limestones of Ariège and the Pyrenees has long been known, and the mode of its occurrence has recently been investigated by Lacroix (17). The lherzolites which are the prevalent igneous rocks of the district appear to have been intruded prior to the deposition of the Upper Jurassic strata, which contain pebbles of the lherzolites. The intrusion of these rocks cannot, therefore, have produced the dipyre which is so frequent in the crystalline limestones of the Upper Jurassic. The limestones of the Middle Lias were, however, cut and metamorphosed by the lherzolites. One type of the metamorphosed rocks consists chiefly of large crystal-plates of dipyre enclosing many flakes of biotite and grains of pyroxene, with abundant sphene and more rarely plagioclase. Another type is very micaceous, irregular crystals of dipyre being disseminated through a mass made up of little flakes of biotite and grains of pyroxene. Rutile,

green spinel, and especially hornblende are locally abundant, and sometimes little crystals of blue tourmaline, an unexpected mineral.

Among other examples we may mention the case, also described by Lacroix, of the Ordovician limestones metamorphosed by the elæolite-syenite of Montreal (18). The limestones become thoroughly crystalline, and their contact with the intrusive rock is marked sometimes by a zone of garnet or cancrinite, sometimes by a granular aggregate of pyroxene, garnet, and wollastonite. The intensity of the metamorphism and the relative proportions of the several minerals formed vary greatly in short distances. There are often patches consisting exclusively of granular silicates, wollastonite, pyroxene, and garnet, sometimes accompanied by felspar and perofskite, intimately associated with the garnet. Here the coming in of such minerals as cancrinite and perofskite (the latter also found near the elæolite-syenites of Arkansas) seems to suggest some degree of connection between the products of metamorphism and the nature of the igneous rock that produced it, which bears on one of the more obscure problems of our subject.

## BIBLIOGRAPHY.

### PART I.

(1) GARDINER, Miss M. I. Contact-Alteration near New Galloway. *Quart. Jour. Geol. Soc.*, vol. xlvi., pp. 569-580, 1890.

(2) BARROW, GEORGE. On an Intrusion of Muscovite-biotite Gneiss in the South-eastern Highlands of Scotland, and its accompanying Metamorphism. *Quart. Jour. Geol. Soc.*, vol. xlix., pp. 330-356, 1893.

(3) HARKER, ALFRED, and MARR, J. E. The Shap Granite and the Associated Igneous and Metamorphic Rocks. *Quart. Jour. Geol. Soc.*, vol. xlvii., pp. 266-327, 1891. Supplementary Notes on the Metamorphic Rocks around the Shap Granite. *Ibid.*, vol. xlix., pp. 359-371, 1893.

(4) SAUER, A. *Erlaüterungen zur geologischen Specialkarte des Königreichs Sachsen.* Section Meissen, Blatt 48, 1889.

(5) DALMER, K. *Ibid.* Section Tanneberg, Blatt 64, 1888.

(6) BECK, RICHARD. *Ibid.* Section Berggiesshübel, 1889; Section Pirna, 1892; Section Kreischa-Hänichen, 1892. Also,

Ueber das Schiefergebirge, etc., der Gegend von Berggiesshübel, etc. *Ber. d. Naturf. Ges. Leipzig*, 1890. Ueber Amphibolitisirung von Diabasgesteinen im Contact-bereiche von Graniten. *Zeits. d. deutsch. geol. Ges.*, vol. xliii., pp. 257-263, 1891. And especially Die Contacthöfe der Granite und Syenite im Schiefergebiete des Elbthalgebirges. *Tschermak's Miner. u. Petrog. Mitth.* (2), vol. xiv., pp. 290-342, 1893.

(7) KIKUCHI, YASUSHI. On Cordierite as a Contact Mineral. *Jour. Coll. Sci. Imp. Univ. Japan* (*Tokyo*), vol. iii., pp. 313-334, 1890.

(8) HARKER, ALFRED. Cordierite in the Lake District. *Geol. Mag.*, pp. 169, 170, 1894.

(9) HUTCHINGS, W. MAYNARD. Notes on the Composition of Clays, Slates, etc., and on some Points in their Contact Metamorphism. *Geol. Mag.*, pp. 36-45, 64-75, 1894.

(10) BECK, RICHARD. Ueber Brookit als Contactmineral. *Neu Jahrb. für Min.*, etc., vol. i., p. 159, 1892.

(11) ROSENBUSCH, H. Zur Auffassung der Chemischer Natur des Grundgebirges. *Tscherm. Miner. Petr. Mitth.* (2), vol. xii., pp. 49-61, 1891.

(12) HORNE, J. On the Contact Metamorphism of the Radiolarian Chert in the Lower Silurian Rocks along the Margin of the Loch Doon Granite. *Report Brit. Assoc.*, for 1892, p. 712.

(13) WILLIAMS, J. FRANCIS. The Igneous Rocks of Arkansas. *Ann. Rep. Geol. Surv. Ark.*, for 1890, vol. ii., Little Rock, 1891.

(14) BONNEY, T. G. The Effects of Pressure on Crystalline Limestones. *Geol. Mag.*, pp. 483-486, 1889.

(15) SOLLAS and COLE. The Origin of Certain Marbles: a Suggestion. *Sci. Proc. Roy. Dubl. Soc.* (2), vol. vii., pp. 124-126, 1891.

(16) BRÖGGER, W. C., and BÄCKSTRÖM, H. Die Mineralien der Granatgruppe. *Zeits. für Kryst.*, vol. xviii., pp. 209-276, 1890.

(17) LACROIX, A. Sur les modifications minéralogiques effectuées par la lherzolite sur les calcaires du jurassique inférieur de l'Ariège. *Comptes Rendus*, vol. cxv., pp. 974-976, 1892.

(18) LACROIX, A. Sur la syénite éléolithique de Montréal (Canada) et sur les modifications de contact endomorphes et exomorphes de cette roche. *Comptes Rendus*, vol. cx., pp. 1152-1154, 1890.

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# ON THE KINETIC THEORY OF GASES.[1]

IN the former of the two works which I have taken for the subject of this article, Dr. Watson has given us a clear account of the established results of the kinetic theory. He has also pointed out the nature of some of the difficulties of the theory and given valuable suggestions for their solution.

In Professor Tait's work, as yet unfinished, we have the advantage of seeing the subject from a different point of view. He has ventured a little farther than Dr. Watson into the regions of hypothesis. He has also discussed the difficult subjects of diffusion and viscosity in gases, with which Dr. Watson, following his original plan, has not attempted to deal.

In discussing doubtful points I shall have to refer to the arguments of these writers, and if this is done with some abbreviation, I hope that the reader will supply the defects of my exposition by reference to the originals.

1. The simplest conception of a gas in the kinetic theory is that of a number of perfectly elastic spheres moving within an elastic bounding surface. If $p$ denote pressure per unit of surface, $v$ volume, T the mean kinetic energy of a sphere, the equation $pv = CT$ (A) is accurate, provided that the spheres be mere particles, having mass but no sensible diameters.

2. The laws of Boyle and Charles, which hold approximately for hydrogen and other permanent gases under ordinary conditions, are concisely expressed by the equation $pv = Ct$ (B), in which $t$ is the absolute temperature. The complete agreement of (A) and (B) suggests the kinetic theory, according to which the molecules of a gas are to be regarded as elastic spheres, and the absolute temperature is measured by their mean kinetic energy.

[1] *A Treatise on the Kinetic Theory of Gases*, by H. W. Watson, D.Sc., F.R.S., second edition, Clarendon Press, Oxford, 1893. "On the Foundation of the Kinetic Theory of Gases," parts i.-iv., by Professor Tait, *Transactions of the Royal Society of Edinburgh.*

3. If the spheres have sensible diameter, collisions will occur among them, and we require a law of distribution of velocities. It will be the well-known exponential or Maxwellian law, $\epsilon^{-hmu^2}$ being the chance of velocity $u$ in given direction for a sphere of mass $m$. And if the spheres have room enough the chances are all independent. The permanence of this distribution, once established, has been proved by several writers.

I shall make some use of the following notation :—

Let V be the velocity of the common centre of gravity of a pair of spheres, $\rho$ their relative velocity. Then if collisions occur at haphazard, it is a property of the sphere that all directions of $\rho$ after collision are equally probable. It is a property of the above distribution of velocities that for given magnitude and direction of V and given magnitude of $\rho$, whether the pair of spheres collide or not, all directions of $\rho$ are equally probable. This proves the permanence of the distribution if any further proof were wanted. If this law is obeyed, the system is "undisturbed," or, in Professor Tait's language, is in the "special state". If it be not obeyed there is a "disturbance," and the effect of collisions is to remove the disturbance and reduce the system to the "special state".

4. Boltzmann was the first to show that the "special state" is, in the absence of external forces tending to produce disturbance, not only a sufficient, but a necessary, condition for permanence. For that a certain function B is always diminishing with the time, and then only becomes constant when the special state is attained.

5. If all the spheres in a certain volume have given to them, in addition to their molecular velocities in the special or undisturbed state, any common velocity $u$ in any direction, whether $u$ be great or small, the law of uniform distribution in direction of the relative velocities is unaffected. So a gas in this state is undisturbed. Professor Tait calls this "mass motion" of the gas.

6. One of the most useful forms in which to express the permanent character of the motion is the virial equation—

$$\tfrac{3}{2}pv = \Sigma\tfrac{1}{2}m\overline{u^2} + \tfrac{1}{2}\Sigma\Sigma \mathrm{R}r$$

in which R denotes the *repulsive* force, $r$ the distance, be-

tween a pair of spheres, and the summation includes all pairs. If the spheres be material particles without sensible dimensions $\Sigma\Sigma \mathrm{R}r$ vanishes, there being no finite forces. If they be spheres of diameter "$\varsigma$," and subject to collision, $\Sigma\Sigma \mathrm{R}r$ is proportional to $\Sigma m\overline{u^2}$. For consider two equal spheres A and B, each of mass $m$. Let $\rho$ be their relative velocity. About the centre of A describe a sphere with radius $\varsigma$, *i.e.*, twice the radius of A or B. Consider all radii of that sphere which make with $\rho$ angles between $\theta$ and $\theta + d\theta$. Let $v$ be the volume in which the spheres, $n$ in number, are supposed to move. Then the chance that the centre of B shall at a given instant be within the element of volume $2\pi\varsigma^2 \cos\theta \sin\theta \, d\theta \, \rho dt$ is $\dfrac{2\pi\varsigma^2 \cos\theta \sin\theta \, d\theta \, \rho dt}{v}$

and if this is the case, A and B will collide within the time $dt$ after the given instant, and the relative velocity in line of centres, namely, $\rho \cos\theta$, will be reversed. Suppose that reversal to be affected by the large finite force $\dfrac{m\rho \cos\theta}{2dt}$ acting on each sphere during the time $2dt$, then R, in the expression R$r$, is $\dfrac{m\rho \cos\theta}{2dt}$; also $r = \varsigma$, and the number of pairs of spheres in volume $v$ is $\dfrac{n^2}{2}$; so

$$\Sigma\Sigma \mathrm{R}r = \frac{n^2}{2v} m 2\pi\varsigma^3 \overline{\rho^2} \int_0^{\frac{\pi}{2}} \cos^2\theta \sin\theta \, d\theta$$

$$= \frac{n^2}{2v} m \tfrac{2}{3} \pi\varsigma^3 \overline{\rho^2}$$

$$= \frac{n^2}{v} m \tfrac{2}{3} \pi\varsigma^3 \overline{u^2},$$

because $\overline{\rho^2} = 2\overline{u^2}$, and since $\Sigma m\overline{u^2} = nm\overline{u^2}$ the virial equation becomes

$$3pv = \Sigma m\overline{u^2} \left(1 + \frac{2n}{3} \frac{\pi\varsigma^3}{v}\right) = \Sigma m\overline{u^2} \left(1 + \frac{nv'}{v}\right) \text{ if } v' = \tfrac{2}{3} \pi\varsigma^3, \text{ or}$$

four times the volume of one of the $n$ spheres. The effect is that if the gas were compressed at constant temperature, the pressure would increase rather *more rapidly* than it should do were the law $pv = \mathrm{C}t$ accurate. In fact the deviations from the laws of Boyle and Charles that require explanation are in the opposite direction.

7. It is worth while to analyse more closely the conception of an elastic sphere. Our elastic spheres are supposed to have each three degrees of freedom, namely, that of motion of translation in space. The three angular velocities of which each sphere is also capable are to be ignored, because, the spheres being perfectly smooth, these velocities will not be affected by collisions. Again, if our spheres collide with each other, they must separate with their combined kinetic energy unaltered, none of it being dissipated, *i.e.*, converted into heat or vibrations. This is essential if the system is to have the properties of a permanent gas. For otherwise it would change its condition by collisions among the spheres without any influence of external bodies. It would appear then that a sphere, or molecule, such as the theory requires, cannot consist of parts capable of vibrations or other relative motion *inter se*, for otherwise such relative motion would be set up on collision. Therefore, also, that it cannot of itself be either hot or cold, that is, cannot possess the quality temperature as commonly understood. But the whole system of moving spheres has temperature, which, according to the above form of the theory, either is, or is proportional to, the mean kinetic energy of the spheres.

8. It is evident that a body of such very simple structure cannot be expected to discharge all the duties which the chemist requires of the molecules of a gas. Further we know from the phenomena of the spectroscope that the molecules, or atoms, of every gas must be capable of executing vibrations of one or more kinds. It seems then that our system of elastic spheres, though it satisfies with more or less accuracy certain physical properties of permanent gases, which depend on pressure, density and temperature, cannot be expected to explain those phenomena which depend on chemical composition.

9. The following extension of the theory was given originally by Boltzmann, and afterwards in the most general form in the first edition of Dr. Watson's book. For the elastic sphere with its three degrees of freedom we may substitute a molecule of $n$ co-ordinates, $q_1$, $q_2$, $q_n$, and corresponding momenta $p_1, p_2, p_n$, and in the permanent state

of an infinite number of such molecules sparsely scattered, the chance that any given one shall have co-ordinates between the limits

$$\left.\begin{array}{l} q_1 \text{ and } q_1 + dq_1 \\ q_2 \text{ and } q_2 + dq_2 \\ \text{etc.,} \end{array}\right\} \qquad (a)$$

and momenta between the limits

$$\left.\begin{array}{l} p_1 \text{ and } p_1 + dp_1 \\ p_2 \text{ and } p_2 + dp_2 \\ \text{etc.,} \end{array}\right\} \qquad (b)$$

in proportional to

$$\varepsilon^{-h(\chi+T)}\, dq_1 \ldots dp_n$$

where $\chi$ is the potential, T the kinetic energy in the state $(ab)$. This is the general law of permanence of which the $\varepsilon^{-hmu^2}du$ of elastic spheres is a particular case.

10. We must consider the assumptions on which this theorem rests. Let $f(q_1 \ldots p_n)\, dq_1 \ldots dp_n$ be the number of molecules in unit of volume between the limits "$a$" "$b$" above, or the chance that a given molecule shall be between those limits, and let $F(Q_1 \ldots P_n)\, dQ_1 \ldots dP_n$ be the number between the corresponding limits

$$\left.\begin{array}{l} Q_1 \text{ and } Q_1 + dQ_1 \\ Q_2 \text{ and } Q_2 + dQ_2 \\ \text{etc.,} \end{array}\right\} \qquad A$$

and

$$\left.\begin{array}{l} P_1 \text{ and } P_1 + dP_1 \\ P_2 \text{ and } P_2 + dP_2 \\ \text{etc.,} \end{array}\right\} \qquad B$$

The number of pairs, one from each set, is shortly $fF dq_1 \ldots dP_n$. Let these values of the variables denote the state in which mutual action between the pair commences. Such a pair will in time $\tau$ pass by their own mutual actions, uninfluenced by any third molecule, into the state

$$\left.\begin{array}{l} q'_1 \text{ and } q'_1 + dq'_1 \\ q'_2 \text{ and } q'_2 + dq'_2 \\ \text{etc.,} \end{array}\right\} \qquad (a')$$

and

$$\left.\begin{array}{l} p'_1 \text{ and } p'_1 + dp'_1 \\ p'_2 \text{ and } p'_2 + dp'_2 \\ \text{etc.,} \end{array}\right\} \qquad (b')$$

for the first, and

$$\left.\begin{array}{l} Q'_1 \text{ and } Q'_1 + dQ'_1 \\ Q'_2 \text{ and } Q'_2 + dQ'_2 \\ \text{etc.,} \end{array}\right\} \qquad A'$$

and

$$\left.\begin{array}{l} P'_1 \text{ and } P'_1 + aP'_1 \\ P'_2 \text{ and } P'_2 + dP'_2 \\ \text{etc.,} \end{array}\right\} \qquad B'$$

for the second molecule. Let this be the state when mutual action ceases.

Let $f'dq'_1 \ldots dp'_n$ be the number per unit of volume of molecules in the state $a'$ $b'$, and $F'dQ'_1 \ldots dP'_n$ the number in the state A' B'. Then shortly $f'F'dq'_1 \ldots dP'_n$ is the number of pairs in the second state.

It is now required that the number of pairs in the first state shall be the same as in the second, that is, $fFdq_1 \ldots dP_n = f'F'dq'_1 \ldots dP'_n$. This has been shown by Boltzmann to be necessary for permanence. But since $q'_1 \ldots P'_n$ are functions of $q_1 \ldots P_n$ and of the time $\tau$ and no other quantities whatever, $dq_1 \ldots dP_n = dq'_1 \ldots dP'_n$. Therefore our requirement is satisfied if $fF = f'F'$.

11. If this equation be given only for *particular values* of the variables $q_1 \ldots P'_n$, we cannot draw from it any inference concerning the form of the functions $f$ and F. But if it be satisfied for all possible initial values of the variables $q_1 \ldots P_n$ with the final values $q'_1 \ldots P'_n$ into which they pass under the influence of their mutual action alone, we can infer that the form of the function is $f = F = Ce^{-h(\chi + T)}$.

12. The theorem, as given by Watson, thus depends on three conditions: (1) There must be an infinite number of pairs, including all possible combinations of the variables; and (2) each pair must be uninfluenced by any third molecule during the time of action of the mutual forces between its members. (3) The fact of the near approach of the two molecules to one another, which is implied in their encounter, must not of itself destroy the independence of the chances $f$ and F. This condition involves the property mentioned above that the molecules must be "sparsely scattered". For, if they be crowded, this independence

will be interfered with, as regards at least the velocities of translation (see *post* 34). Condition (2) is assumed to be always satisfied by the molecules of a very rare gas. As the gas becomes denser, we arrive at a state in which no molecule or group of molecules is ever free from the influence of other molecules not belonging to the group. Condition (2) now fails, and the proof, as above given, fails, whether the law continues to hold or not.

13. For the above conditions Boltzmann would substitute the following, namely, that a single system shall, if left to itself, at some time or other pass through every combination of the co-ordinates and velocities which can be reached from its initial state consistently with the conservation of energy. And he would, I think, express the law by saying that on average *the time* during which the co-ordinates and velocities are between the limits "$a$" and "$b$" above varies as $\epsilon^{-h(\chi+T)}\, dq_1 \ldots dp_n$. It seems to me to be open to question whether this method would succeed in any case where the other would fail. See an interesting paper of his in the *Philosophical Magazine* for March, 1893, in which he discusses a test case suggested by Lord Kelvin.

14. For the present it is sufficient to point out a particular consequence of the $\epsilon^{-h(\chi+T)}$ distribution, namely, that if a gas consists of stable molecules, each having $n$ co-ordinates, including three of position in space, then $\frac{\text{energy of translation}}{\text{whole kinetic energy}} = \frac{3}{n}$ on average. (It will be observed that we have at this point introduced a fourth condition besides (1), (2) and (3), namely, that the molecules are to be *stable* systems.) To prove this, consider that T, the kinetic energy of a molecule, is a quadratic function of the velocities of the form $2T = m(\dot{x}^2 + \dot{y}^2 + \dot{z}^2) + a_1\dot{q}_1^2 + b_{12}\dot{q}_1\dot{q}_2$ + etc., where $x$, $y$, $z$, are the co-ordinates of position, $q_1 \ldots q_{n-3}$, the remaining co-ordinates, and $\dot{x}\ \dot{y}\ \dot{z}\ \dot{q}_1 \ldots \dot{q}_{n-3}$, etc., the corresponding velocities, and $a_1\ b_{12}, \ldots$ etc., are generally functions of the co-ordinates.

Now, according to the theorem, if we consider all those molecules for which the co-ordinates $x \ldots q_n \ldots$ etc., have given values, but the velocities may have any values between $+\infty$ and $-\infty$, we can find the mean values of

$\dot{x}^2, \dot{y}^2, \dot{z}^2, \dot{q}_1^2, \dot{q}_2^2, \ldots$ etc., and also of the products $\dot{q}_1\dot{q}_2, \ldots$ etc., by integrating the expressions—

$$\epsilon^{-h(m\dot{x}^2+m\dot{y}^2+m\dot{z}^2+a_1\dot{q}_1^2+b_{12}\dot{q}_1\dot{q}_2+\ldots)}\,\dot{x}^2\,d\dot{x}\,d\dot{y}\,d\dot{z}\,d\dot{q}_1, \quad \ldots$$

etc., between the limits $\pm\infty$ for each variable. The result is as follows :—

Form the determinant

$$d = \begin{vmatrix} 2m & & & & \\ & 2m & & & \\ & & 2m & & \\ & & & 2a_1 & b_{12} \ldots b_{1n-3} \\ & & & b_{12} & 2a_2 \ldots b_{2n-3} \\ & & & \ldots & \ldots \\ & & & & 2a_{n-3} \end{vmatrix}$$

And let $d_{11}\ d_{12}\ d_{22}$, etc., be its minors. Then we find

$$\overline{\dot{x}^2} = \overline{\dot{y}^2} = \overline{\dot{z}^2} = \frac{d_{11}}{hd} = \frac{d_{22}}{hd} = \frac{d_{33}}{hd}$$

$$\overline{\dot{q}_1^2} = \frac{d_{44}}{hd} \quad \ldots \quad \overline{\dot{q}_1\dot{q}_2} = \frac{d_{45}}{hd}, \text{ etc.,}$$

and therefore $m\overline{(\dot{x}^2+\dot{y}^2+\dot{z}^2)} = \frac{3}{2h}$,

also $a_1\overline{\dot{q}_1^2} + b_{12}\overline{\dot{q}_1\dot{q}_2} + \text{etc.}, = \frac{n-3}{2h}$.

Therefore $m\,\frac{\overline{(\dot{x}^2+\dot{y}^2+\dot{z}^2)}}{a_1\overline{\dot{q}_1^2} + b_{12}\overline{\dot{q}_1\dot{q}_2} + \text{etc.}} = \frac{3}{n-3}$.

or $m\,\frac{\overline{(\dot{x}^2+\dot{y}^2+\dot{z}^2)}}{2\mathrm{T}} = \frac{3}{n}$

It is not generally true that $a_1\overline{\dot{q}_1^2} = a_2\overline{\dot{q}_2^2}$, etc. But it is possible, for given values of the co-ordinates, by a linear transformation to reduce the quadratic function to the form $a_1\dot{q}'^2_1 + a_2\dot{q}'^2_2$, etc., containing no products $\dot{q}'\dot{q}'$, and these quantities $q'$ have the property that $a_2\overline{\dot{q}'^2_1} = a_2\overline{\dot{q}'^2_2} =$ , etc., if in this form they are of any use. The proof that $m\,\frac{\overline{(\dot{x}^2+\dot{y}^2+\dot{z}^2)}}{2\mathrm{T}} = \frac{3}{n}$ does not depend on the transformation.

15. It follows from this theorem, as shown first by Maxwell, and as explained in Watson's book, that for a gas

whose molecules are stable and have $n$ degrees of freedom, the ratio of the specific heat at constant pressure to that at constant volume is $\gamma = \frac{n+2}{2}$, or $\frac{n+2+\epsilon}{n+\epsilon}$, where $\epsilon$ is a small quantity necessarily positive, that is $\gamma$ is, or is rather less than, $\frac{n+2}{n}$.

Now it would seem that the molecules (or atoms) of any gas may have, in addition to three degrees of freedom of motion in space, perhaps as many more as the spectrum of the gas contains lines. And if that be the case, $\frac{n+2}{n}$ can on no probable hypothesis be made to represent the observed values of $\gamma$.

16. One possible solution of this difficulty is, I think, the following: in deducing the value of $\gamma$ from the law $\epsilon^{-h(\chi+T)}$ we have assumed that our gas consists only of *stable* molecules, each having the given number of degrees of freedom. Each molecule is then a system which, when left to itself, is in stationary motion. On that hypothesis the virial equation may be put in the form $\frac{3}{2}pv = \frac{3}{n}T + \left[\frac{n-3}{n}T - \frac{1}{2}\Sigma\Sigma R r\right]$, the terms within the bracket denoting respectively the energy of relative motion of the constituent parts of the molecules, and the mutual forces acting between them, R being now positive when attractive. If the molecule be stable, the two terms within the bracket cancel each other, and we have left $\frac{3}{2}pv = \frac{3}{n}T$, which leads us into difficulties in the form $\gamma = \frac{n+2}{n}$. But if the molecule be unstable $\frac{1}{2}\Sigma\Sigma R r < \frac{n-3}{n}T$. And therefore $\frac{3}{2}pv > \frac{3}{n}T$. We thus get rid of the particular difficulty, only perhaps to introduce others which may prove as formidable. On this view the gas will consist not of stable molecules only, but of molecules with a considerable admixture of dissociated atoms.

17. The following has also been suggested as a mode of

escape from the difficulty: In the proof of the law $\epsilon^{-h(\chi+T)}$ we assumed that the final co-ordinates and momenta $q'_1 \ldots P'_n$ were functions of the initial co-ordinates and momenta and of no other quantities whatever. But suppose the molecule contains a class of co-ordinates $a_1 \ldots a_n$, with corresponding momenta $\beta_1 \ldots \beta_n$, which are not functions at all of the other co-ordinates and momenta $q_1 \ldots P_n$, but entirely independent of them. If that be so $\chi + T$ in the expression $\epsilon^{-h(\chi+T)}$ is the energy of the $qp$ co-ordinates and momenta only, and will not include the $a\beta$ system. It is true that the $a\beta$ set may be amenable to the same treatment, and we might perhaps prove that for them also the law of distribution is denoted by $\epsilon^{-k(\chi'+T')}$ where $\chi'$ is the potential, T′ the kinetic energy of the system $a\beta$. But we cannot prove that $h = k$. And so the ratio $\frac{m(\dot{x}^2+\dot{y}^2+\dot{z}^2)}{2T}$ need not depend on the number of co-ordinates of the $q$ set and the $a$ set respectively. On this assumption we may make $\frac{m(\dot{x}^2+\dot{y}^2+\dot{z}^2)}{2T} \neq \frac{3}{n}$, if $n$ and T relate to all the co-ordinates both of the $q$ and $a$ sets.

The hypothesis cannot be unreasonable, because all writers on the kinetic theory of gases have made it once, when they ignore the rotation of their elastic spheres. The three angular velocities of a smooth sphere behave to the translation velocities exactly in the same way as $\beta$ to $p$ on the above hypothesis. And a system in which the translation velocities are distributed according to the law $\epsilon^{-hu^2}$, and the angular velocities according to $\epsilon^{-kw^2}$, would, if the spheres be smooth, be in equilibrium with $h \neq k$. But the following objection appears to be fatal: If the temperature of the gas depends on the $qp$ system alone, including the velocities of translation, you must on this hypothesis admit that of two equal quantities of gas at the same pressure and temperature, one might contain more energy than the other because it might contain more of the $a\beta$ sort. If temperature depends on both forms of energy, then one must, under some circumstances, be capable of conversion into the other,

because we can raise the temperature by compression alone. So $\alpha$ $\beta$, etc., cannot be independent of $q$ $p$, etc.

18. A step towards the solution of the difficulty, and one which may prove to be important, is taken in Watson's book. He shows, namely, that although the condition for permanence is never attained until the distribution of momenta is according to the law $\epsilon^{-h(\chi+T)}$, and any disturbance is gradually effaced by encounters between the molecules, the function B always approaching its minimum, yet *the rate at which this process takes place* depends entirely on the nature of the disturbance. If, for instance, the disturbance consists in giving to spheres of mass $m$ greater average energy of translation than those of mass M in a mixture otherwise normal, and under ordinary conditions of pressure, etc., it will be reduced, as Tait has shown, to half of its original amount in a very small fraction of a second. On the other hand, suppose the system of elastic discs described in Watson's book, or a system of elastic spheres, the centre of gravity of each sphere instead of being at the centre of figure, being at a small distance $c$ therefrom. According to the above law the spheres should have energy of rotation on average equal to that of translation. Let the disturbance consist in a small inequality in these average energies. It will be effaced gradually by collisions, but at a rate per unit of time proportional to $c^2$, and therefore as slowly as we please.

19. This fact alone will not help us much, because we cannot suppose that the gas subjected to experiments for determining $\gamma$ has not had time during the experiment to attain to its permanent condition. But if it could be shown that any cause exists always increasing the energy of translation and diminishing that of vibration, and so creating a disturbance, while encounters are always effacing the disturbance, the fact that the rate of effacement is very slow may be of great importance. For let $\frac{\delta f}{\delta t}$ be the rate at which the disturbance $f$ is produced by the unknown cause, $\frac{df}{dt}$ the rate at which it is destroyed by encounters.

Then $\frac{df}{dt} = -Kf$, where K is a constant depending on the constitution of the body. And the actual constant value of $f$ will be given by the equation $f = \frac{1}{K}\frac{\delta f}{\delta t}$. And $f$ may be considerable if K be small. But where are we to look for the supposed disturbing cause? Clearly it cannot be looked for in any mutual actions of the gas molecules; for that is always effacing the disturbance already existing. It can be looked for (if at all) only in the action between the gas and external bodies.

20. Now we have appealed to the spectroscope as proving that our molecules have many degrees of freedom, because they, or their constituent atoms, communicate vibrations of many kinds to the luminiferous ether, and are capable of receiving from the ether vibrations of the same kinds. The vibration energy or internal energy of our molecules is thus capable of transmission by what we call radiation from these molecules to external bodies. It is our duty also to believe that some of it is scattered into infinite space and so lost to science, as much as if it ceased to exist, *quia de non apparentibus et non existentibus eadem est ratio.* On the other hand energy of translation is, so far as we know, incapable, while in that form, of being communicated to the ether.

21. If this be true, it follows that some action is always taking place between the molecules of our gas and external bodies. It may be said that this action will not be sensible except at high temperatures, *i.e.*, when the vibrations are very intense. But according to our theory there is even at low temperatures a minority of molecules in the same state of intense vibration which the majority have at high temperatures. And it may be questioned whether we can, as now the fashion is, treat minorities as non-existent. It is improbable indeed that this interaction between gas molecules and external bodies should be sufficiently important to affect the determination of $\gamma$. But one consequence must, I think, be admitted, *viz.*, that the law $\epsilon^{-h(\alpha+T)}$ can never express with complete accuracy the state of our system. For in our proof of that law we assumed in

condition (2) that our molecules are not interfered with by any body not a member of their own family. But the luminiferous ether is such a body, and therefore, if it have the properties attributed to it of imparting energy to or receiving it from gas molecules, it is itself a part of the material system under discussion, and our conclusions cannot be safe unless we take it into account.

22. It is worth while to note also that no actual gas under experiment can accurately satisfy the condition (2) required by the analysis. For collisions must occur, not only between the molecules of the gas, but between them and the walls of the containing vessel, and in the latter case the condition (2) cannot be satisfied.

23. The solution of this difficulty, when it is discovered, will probably be found intimately connected with the solution of another question in the kinetic theory, namely, What is *the relation between kinetic energy and temperature?* This question has been discussed by Tait, to whose reasoning I shall refer later.

24. *On the deviation of gases from the laws of Boyle and Charles.*

When a gas undergoes compression at constant temperature, it is found that the pressure increases as the volume diminishes *less* rapidly than it would do were the relations accurately expressed by the equation $pv = Ct$. The deviation becomes more marked as the compression increases, and finally a portion of the compressed gas becomes liquid. So that a state is reached in which if any more gas at the same temperature were forced into the same volume, the gas so forced in would all take the liquid form, and the pressure of the still gaseous portion of the substance would be unaltered. The degree of condensation required to produce this result is greater at higher than at lower temperatures; and at a certain temperature, called the *critical temperature* for the substance in question, no degree of condensation converts any of it into liquid, or else the liquid form of the substance is indistinguishable from its vapour. The actual relations between $p$, $v$ and $t$ for certain gases within certain limits have been determined with great accuracy by the researches of Andrews, and more recently

of Amagat. The results obtained by Amagat for $CO_2$ are discussed at length by Tait.

25. Our kinetic theory of gases is bound, if it aspires to be complete, to give some account of these phenomena. The first object to which physicists have turned their attention has been to invent a modified form of the virial equation which should express the properties of an actual gas, as determined by Andrews or Amagat, in the same convenient way in which the equation $pv = Ct$ expresses the properties of the ideal perfect gas. For this purpose it is necessary to introduce into the virial equation certain constants. Van der Waals proposed the equation $\left(p + \frac{a}{v^2}\right)(v - \beta) = \frac{1}{3}\Sigma(mu^2)$ in which $a$ and $\beta$ are two disposable constants, but Tait shows that at least three are necessary. Clausius proposed $p = \frac{kt}{v - \beta} - \frac{a}{t(v + a)^2}$ in which we have three disposable constants $a$, $\beta$ and $a$ (for explanation of $k$ see Tait, part iv., p. 261). Finally Tait gives us $pv = Rt + \frac{C}{v + \gamma} - \frac{A - Rte}{v + a}$. I take his form given, part iv., p. 265, and subsequently modified in notation only. In this $Rt$ is the mean kinetic energy during free path, and, as stated below, $R = \frac{dp}{dt}$.

26. If such an equation can be found, it will be very valuable, perhaps more valuable than a complete kinetic theory. But for a kinetic theory—and that is now our object—we require not only a modified formula accurately expressing the observed facts, but some hypothesis concerning the nature and constitution of gas molecules which shall explain and justify the modified formula. Such a hypothesis Tait has given us, and so far as I know no one else has yet worked out any in detail.

27. His hypothesis is that the molecules behave indeed like conventional elastic spheres when they actually collide with each other, but in addition attract each other with finite force. He assumes further that the effect of that finite force may be approximately represented as follows, dealing with equal spheres only: When two molecules

approaching each other reach the distance $a$ apart (in which $a$ is, of course, greater than $s$, the diameter of a molecule) an impulse acts in the line of centres increasing the square of the relative velocity $u$ by the constant quantity $c^2$, supposed to be independent both of $u$ and of the angle which its direction makes with the line of centres at the instant. When the distance is less than $a$ no force acts. This approach is called *an encounter*. If the value of $u$, and the angle between its direction and the line of centres, be suitably chosen, there will be also an *impact* between the hard nuclei. Whether an impact takes place or not, the molecules will again on separation reach the distance $a$. And then the square of the relative velocity is again diminished by $c^2$. Also $c^2 = \frac{2}{\sqrt{h}}e$, $e$ being one of the constants in Tait's virial equation above given.

28. On this hypothesis, if $c^2$, $a$ and $s$ were all known, the motion of the system for any assigned values of $t$ and $v$ would be determinate, whether our mathematical powers suffice to make all the necessary calculations or not. We should then have only three disposable constants corresponding to $c^2$ $a$ and $s$ to introduce into the virial equation. So comparing Tait's hypothesis with the practical formula which he derives from it, we seem to have in the latter two constants too many. To adapt the hypothesis to the virial equation, we have to find (1) the modification of the term $\Sigma m\overline{u^2}$, (2) that of $\Sigma\Sigma \mathrm{R}r$. Now $\frac{1}{2}\Sigma m\overline{u^2}$, or the mean kinetic energy, is increased, approximately at least, by adding $c^2$ for the number of pairs which at any (and therefore every) instant are at less than distance "$a$" from each other, are in "*entanglement*," as he defines it. The value of $\Sigma m\overline{u^2}$ depends then on the average duration of an entanglement, which he calculates, part iii., p. 1037. The term $\Sigma\Sigma \mathrm{R}r$ has to be modified in two ways. Firstly, calculate the average value of the *attractive* impulse for each encounter, and multiply by the distance "$a$" at which it takes place. That calculation is performed, pages 1033, 1034. The result will be of the opposite sign to the term $\Sigma m\overline{u^2}$. Secondly, remembering that for some encounters

an impact will take place, for others not, calculate the average value of the *repulsive* impulse per encounter, and multiply by "$s$" the distance at which it takes place. The result will be of the same sign as $\Sigma m\bar{u}^2$.

29. Tait's reasoning is as follows: The increase of $\Sigma m\bar{u}^2$, depending as it does on the number of molecules in entanglement at any instant, is proportional to the number of encounters. Now for given volume this is proportional to the square of the density, but for a given number of molecules proportional to the density only, and therefore inversely proportional to $v$. He therefore adds to $Rt$ or E, the term $\frac{C}{v+\gamma}$ where C is positive, and $\gamma$ of uncertain sign. In like manner for the two parts of $\Sigma\Sigma Rr$ he writes $\frac{A}{v+a}$ and $\frac{A}{v+a}\left(Rt+\frac{C}{v+\gamma}\right)$ (part iv., p. 265). I see no objection to this reasoning except that it falls short of Professor Tait's own standard of perfection, because it introduces five disposable constants while the theory allows only three. That, of course, does not detract from the value of the formula as an empirical formula, a concession to the weakness of the flesh. And certainly for the values of the constants assumed, p. 271, the formula gives results agreeing remarkably with those of Amagat. Does it not agree with them more closely than is necessary, considering that the calculated results are, in the matter of the constant $c^2$, only approximate?

30. *The relation between kinetic energy and temperature.* In the original or elastic sphere form of the theory we are compelled to treat kinetic energy of translation as identical with heat, and as a measure of temperature, because it is the only form of energy which we allow our system to possess. When we give our molecules many degrees of freedom, and as many forms of kinetic energy, the question arises, which of the corresponding forms of energy measures temperature? We quieted our consciences for a time by the law $m\frac{(\dot{x}^2+\dot{y}^2+\dot{z}^2)}{T}=\frac{3}{n}$, saying that it did not matter which, because all that is required is a measure, and accord-

ing to that law, either T or $\dot{x}^2 + \dot{y}^2 + \dot{z}^2$, being always in the same ratio to one another, may be taken as the measure. But if we admit, as I think we must, that deviations from this law, small or great, must be always occurring, thanks to the ubiquitous ether or other disturbers of the peace, the question can no longer be evaded. On the whole, the tendency has been still to regard energy of translation as measuring temperature.

31. But to this Tait objects strenuously. I will endeavour to give his reasons. When (he says) there is molecular attraction, the mean kinetic energy increases with the density (which must be admitted on any theory), and so the "sorting demons," as Lord Kelvin calls them, might, by advancing from time to time those portions of an elastic boundary on which no impact is impending, diminish the volume, and so (if kinetic energy is temperature) increase the temperature, without doing any work. But why should they not? The increase of temperature is consistent with the conservation of energy, because it takes place at the expense of potential. And if it be inconsistent with any other law, *e.g.*, the second law of thermodynamics, is not that exactly the object for which Maxwell created the demons, *viz.*, to violate the second law without violating the conservation of energy? Is it not the law of their being? Violation of the second law is only *malum prohibitum.*

32. Tait again says, and I here quote his own words: "Let the contents of equal volumes at different parts of a tali column of gas be compared. In each the pressure may be regarded, so far as it is due to the external potential, as being applied by bounding walls. But the temperature is the same in each, and the only other quantity which is the same in each is E (*i.e.*, R$\ell$). For as the particles are free to travel from point to point throughout the whole extent of the group, the average value of E must be the same for all, and therefore in regions where the density is small, it must be that of free particles, *i.e.*, absolute temperature."

I confess to having some difficulty in following this reasoning. I understand E or R$\ell$ to be the mean kinetic energy of a molecule during free path, and therefore in case

of a very rare medium the whole mean kinetic energy of a molecule, and therefore in that case the measure of temperature. In the case of a vertical column of gas I understand Professor Tait to assert that the constancy of temperature throughout (when the column is in equilibrium) is an axiom. Anyhow it is certain that in case of a rare gas the mean kinetic energy of a molecule is constant throughout the column, and if kinetic energy and temperature are the same thing no question arises. But when the gas becomes denser can it be accepted as an axiom that the temperature is constant?

Assuming it to be so, then if E is also constant throughout, we have sufficient grounds for taking E as the measure of temperature, that is, the mean kinetic energy during free path, instead of the whole kinetic energy. But the proposition that E is constant seems to me to require more proof than is given to it in the above extract. Then it may be asked what becomes of the temperature when the gas is so compressed that there remains no free path, which must surely be a possible condition above the critical temperature. Perhaps Tait would say that the substance must now be regarded as liquid. He goes on to say that for a liquid the temperature is not E but E + C, C being a quantity which is zero at the critical point, and increases with diminishing temperature.

Finally he says (part iv., p. 268): "What has been said above leads us in the succeeding developments to write (so long as we are dealing with vapour or gas) $E = Rt$ where R is now the increase of pressure with temperature under certain ordinary conditions. That is $E = t\frac{dp}{dt}$ or $\frac{dp}{dt} = \frac{E}{E+C}$."

We must now dismiss this subject in the hope that Tait will throw some more light on it in his forthcoming papers.

33. *On a dense medium of elastic spheres.*

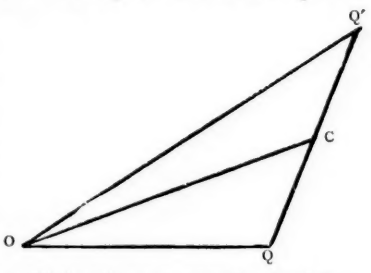
Tait's molecules are elastic spheres, although their motion is much affected by the assumed attractive force between them. It does not appear that any physicist has yet worked out the problem of the motion of a system of elastic spheres as such, when their aggregate volume comes to bear an appreciable proportion to the space in

which they move. Can it be taken for granted that the only effect of increasing density with which we need concern ourselves is the shortening of the mean free path? And if so what is the shortening of the mean path? Tait goes so far as to say that when the density reaches a certain point, an almost discontinuous diminution takes place in the mean free path. For which statement the reader may consult Tait (part iv., p. 265).

34. It appears to me that one effect of increasing density will be that the velocities of spheres which are near to one another will no longer be independent of one another, as in the ordinary rare medium they are assumed to be. Given that sphere A has positive velocity U in any direction, there will be a presumption, becoming greater as the density increases, that a neighbouring sphere B has some positive velocity in that same direction.

That statement can be proved as follows: Suppose a sphere whose velocity is $\omega$ in any direction, say that of $x$, to undergo a collision. What is the value of the expectation of its resolved velocity in $x$ after collision? or (which is the same thing when the spheres are equal) that of the other colliding sphere after collision? Its accurate form can easily be found in the form of an integral for all values of the pre-collision velocity of the other sphere. For the present purpose I need only show that it is positive. Let V be the common velocity, $\rho$ the half relative velocity of the two spheres. Let V = OC, and about C describe a sphere with radius $\rho$.

If $\omega$ = OQ, the pre-collision velocity of the other sphere is OQ′, where QCQ′ is a diameter of the $\rho$ sphere. After collision all directions of the diameter QCQ′ are equally probable. We see that (1) if $V > \rho\sqrt{2}$, the cosine of the angle between the original direction of either sphere and its direction after collision is necessarily positive, (2) if $V < \rho\sqrt{2}$, the value of the expectation of it is positive,



but becomes zero in the limiting case when $\frac{\rho}{V}$ becomes infinite.

35. We can show secondly that the value of the expectation, though positive, is less than $\frac{\omega}{2}$. For if $\omega$, $\psi$ be the vector velocities of the two spheres before collision, their vector velocities after collision are in the notation of quaternions $\frac{\omega + \psi}{2} \pm \rho$, where $\rho$ is a vector whose tensor is that of $\omega - \psi$, and for which all directions are equally probable.

Consequently the average direction for either is that of the vector $\frac{\omega + \psi}{2}$; and since $S\omega\psi$ is on the average negative, the resolved part in direction $\omega$ is on average less than $\frac{\omega}{2}$.

36. We might call the original velocity $\omega$ the *parent*, and the two after-collision velocities the *children*, and so in relation to the velocities acquired in subsequent collisions, $\omega$ is the *ancestor* and the others *descendants*. And we might say that the quality of the ancestor, *viz.*, positive velocity in $x$, survives to the descendants with intensity diminished at each generation, but this is true only on average, because at each generation is introduced a large element of chance in the vector $\rho$. If, therefore, sphere A have positive velocity $\omega$ in $x$, the chance that another sphere B shall have positive velocity in that direction is increased if it be given that (in the above notation) the velocities of A and B have a common ancestor. Just as the expectation that a man now at Cambridge may become a distinguished mathematician would be increased if we knew that he and Professor Tait had a common ancestor.

37. To apply this doctrine to our elastic spheres. Suppose a number of them to be contained within a small imaginary spherical surface S. If they be very closely packed, so to speak, they will for the most part not escape into the surrounding medium without first undergoing many collisions with one another, and so without their velocities, to continue my metaphorical language, becoming related to one another. And their velocities will be no longer independent.

Otherwise we may express it thus: If there be N spheres within S, the chance that their common centre of gravity shall have velocity U . . . U + $d$U in $x$ is in the rare medium proportional to $\varepsilon^{-Nh\mathrm{U}^2}d\mathrm{U}$, because in the rare medium the velocities are all independent. If now the surface S were an elastic boundary, the N spheres would by their collisions with it and with one another in a very short time acquire what Tait calls "mass motion" with velocity U in $x$, their relative velocities being those of a system of elastic spheres in the special state, see (5) above. But remove the elastic boundary and they will in the rare medium escape out of S, and mix with the surrounding spheres, in much less time than it takes them to subside into mass motion.

But in the dense medium the process of diffusion or escape out of S is slower, and the process of acquiring mass motion more rapid. So, as you increase the density, you increase the chance that for neighbouring spheres the velocities have a common ancestor or many such, and therefore the chance that they are coincident in direction. The spheres will develop a tendency to move together in masses, to form "streams" in fact.

38. In such a medium the chance that the N spheres within S shall have respectively $x$ velocities $u_1$ . . . $u_2$ . . . $u_\mathrm{N}$ is not, as it would be on the ordinary hypothesis, represented by $\varepsilon^{-h(u_1^2+u_2^2+\ldots+u_k^2)}$ but will be of the form

$$\varepsilon^{-a_1 u_1^2 \text{ etc.}}\left(a_1u_1^2+b_{12}u_1u_2+a_2u_2^2+\text{etc.},\right)$$

in which the co-efficient $b_{rs}$ will vanish if the spheres to which $u_r$ and $u_s$ relate are not very near each other. And it will be found that the energy of the motion of the common centre of gravity of the group, *i.e.*, the energy of stream motion, bears a larger proportion to the whole energy of the group than it would do if the chances were all independent.

39. To work out this problem in a mathematical form would be very difficult. I can do no more within the limits of this article than indicate what, as appears to me, the general character of the motion will be. I hope that the long delay in the appearance of the concluding parts of Professor Tait's work is due in part at least to the fact

that he is working out a complete theory of a dense medium of elastic spheres.

40. We might perhaps carry the doctrine of "streams" farther. Such a stream as above supposed is always dissolving, the spheres comprising it escaping by diffusion into the surrounding medium, just as we are told the particles of water which form a visible cloud in the sky are not the same from instant to instant. And the state of equilibrium would be when streams form as fast as they are dissolved. But the energy of relative motion of the spheres forming a stream may be a little greater or less. The less it is, the less is the tendency to diffuse, and the longer the stream survives. So that in the case of equilibrium we should expect to find that those parts of the system which have stream motion in the highest degree would on the average have less energy of relative motion, and therefore greater density.

41. The following system would not indeed be in complete equilibrium, but might not require any great force to maintain it, namely, a number of dense masses moving in a comparatively rare medium, the spheres of the rare medium having considerably greater mean kinetic energy than that of relative motion of the spheres within one of the dense masses. So that if one of the dense masses were surrounded by an elastic envelope, the external pressure on that envelope due to spheres of the rare medium with higher mean velocities should be equal to the internal pressure due to the dense medium within. If there were an elastic envelope equilibrium would be complete. In the absence of an envelope the spheres of the dense masses would escape, but only by the comparatively slow process of diffusion at constant pressure.

42. Now I have assumed the molecules to be merely elastic spheres. If, as Professor Tait supposes, they also attract each other with finite force, that molecular attraction might overcome the tendency to diffuse, and the system described in the last paragraph might be permanent.

S. H. Burbury.

fp memoirs as text only

# THE ETHNOGRAPHY OF BRITISH NEW GUINEA.

## II. A GUIDE TO THE LITERATURE.

A VALUABLE *Bibliography of New Guinea* was compiled by Mr. E. C. Rye in 1884 (*Roy. Geogr. Soc. Suppl. Papers*, i.), and this has been brought up to date by Herr J. D. E. Schmeltz in 1893; but the latter author has done more than this, he has added a number of distributional and bibliographical notes to the Memoir which he has collaborated with F. S. A. de Clercq, and has given tables showing the distribution of a large number of Papuan objects and customs. In the appended bibliography will be found the more important works of Dr. O. Finsch, to whom students of the anthropology of the Western Pacific are so greatly indebted; no one interested in Papuan ethnography can dispense with his *Samoafahrten*, the *Ethnological Atlas*, or the highly important series of papers in the *Annalen des k. k. naturhist. Hofmuseums* of Vienna, from 1888-1893. The *Ethnographical Album of the Pacific Islands*, drawn by J. Edge-Partington, is as invaluable to students of ethnology as it is to collectors and curators. The Rev. W. G. Lawes, of Port Moresby, has taken a large number of most excellent photographs illustrating Papuan ethnology, and he has generously deposited the negatives with Mr. H. King, George Street, Sydney, N. S. Wales, in order that anthropologists might have the opportunity of purchasing authentic photographs. Mr. J. W. Lindt, of Melbourne, too, has numerous beautiful photographs; but the best of these are now published in his *Picturesque New Guinea*. The present writer has in the press a memoir describing and illustrating the decorative art of the natives of British New Guinea, in which will also be found descriptions and classifications of implements, etc., and a compilation of many ethnographical data. Mr. J. P. Thomson has compiled a book

entitled *British New Guinea* from Sir William Macgregor's despatches; he gives only a *résumé* of these, omitting other people's labours. Mr. S. H. Ray has studied all the available material on the languages of the Possession.

The foregoing works deal more or less imperfectly with the whole or a considerable portion of the Protectorate. I have not alluded to publications such as articles in encyclopedias and the like, which are compilations from the less recent literature, and I have omitted numerous books and papers which are of little or no interest to anthropologists.

On analysing the literature it is evident that most of our valuable information is due to but a small number of naturalists and missionaries. Amongst the former I need only mention the names of Jukes, Macgillivray, D'Albertis, and Finsch, and of the latter Gill, Lawes, and Chalmers, have alone availed themselves of their unique opportunities, Macfarlane has put only a very few facts on record, the other British missionaries have done absolutely nothing for science. A few observations were made many years ago by the Marist missionaries on Woodlark Island, and recently the Jesuit missionaries on Yule Island and on the St. Joseph River have published some interesting facts.

Most of the expeditions undertaken for scientific purposes, or as newspaper enterprises, have added very few and in some cases no new ethnographical data. A few travellers—Moresby (1876), Comrie (1876), W. Y. Turner (1878), Stone (1880), Basil Thomson (1889), Forbes (1890)—have made small but valuable contributions to Papuan ethnography; but the bulk of those who have published papers or books have made extremely few original observations. Two authors, "Captain Lawson" and L. Trégance,[1] have invented "facts," their books being entirely false!

[1] *Adventures in New Guinea, the narrative of Louis Trégance, a French sailor, nine years in captivity among the Orangwōks, a tribe in the interior of New Guinea.* Edited by Rev. H. Crocker: London, 1876.

Three traders only have directly given to science the benefit of their experience; these are E. G. Edelfeld (1887), E. Beardmore (1890), and W. Tetzlaff (1892); but A. Goldie has verbally given much information to travellers, who have not duly acknowledged the source of their facts, and Robert Bruce has been of great assistance to the present writer.

The Government officials connected with British New Guinea have done lamentably little for anthropology, with the exceptions of Hugh Romilly and Sir William Macgregor. The latter, judging from what I have seen of his writings and have read and heard about him, appears to be a model administrator, and the sciences of anthropology, botany, geography, geology, and zoology are greatly indebted to his energy and ability.

In the following guide to the literature on British New Guinea I begin at the west and finish at the coast boundary of Kaiser Wilhelms-Land. I have also added a few references to the German and Dutch possessions.

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The present writer has brought together practically all that has been published, with additional information, on the two tribes inhabiting the islands of **Torres Straits**, and he will shortly bring out a monograph on these people which will be published by the Cambridge University Press. The craniological data are papers by Turner (1880) and Oldfield Thomas, and the measurements by Quatrefages and Hamy in *Crania Ethnica* and by Flower in the *Catalogue of the Royal College of Surgeons.*

There can be little doubt that the islanders must be regarded as essentially Papuans, though they are not typical; for example, according to some unpublished measurements, they have massive skulls, on the border-line between mesaticephalic and brachycephalic, whereas the measurements of fourteen Daudai skulls give a dolichocephalic index of seventy-one. These results do not agree with those of Oldfield Thomas in his excellent paper, but it is probable he was dealing with some Daudai as well as island skulls. Quatrefages and Hamy (pp. 207-210, 253-256) have drawn

attention to the mixture of races that occurs here. In appearance, intelligence, excitability, handicrafts and most of their customs, the islanders are also unmistakably Papuan.

The mainland between the Dutch boundary and the Fly River has been explored by several people, and is now being pacified by Sir Wm. Macgregor. In Beardmore's paper (1890), and in the notes which follow, will be found an account of the Daudai (**Mowatta**, etc.) people (*cf. C. A.*, 1, 1893, p. 35). Macgregor (*C. A.*, 1, 1892, p. 43) discovered the **Dabulai**, who inhabit the country opposite Saibai Island, and who are said to have affinities with the Western tribe of Torres Straits. In the same report he alludes, amongst other tribes, to the **Masingara**, who chew kava (*cf. J. A. I.*, xxi., 1891, p. 204; D'Albertis, ii., p. 197). The first accurate account of the Mai- and Wassi-Kussa Rivers is that by C. E. Strode Hall (*C.*, 5883, 1890, p. 213). Strachan's account apparently is very misleading. For accounts of **Tugeri** head-hunters, who come from Netherlands New Guinea to ravage the coasts and islands of the British Protectorate, *cf.* Haddon (1891); Macgregor (*C. A.*, 105, 1890, pp. 68-75; *J. A. I.*, xxi., 1891, p. 200; *C. A.*, 1, 1893, pp. 50-53). Little is known of the coast between Mowatta and the Fly River or of the adjacent islands (*cf. C.*, 6323, 1891, pp. 116-118; *The Arch. Rev.*, iii., 1889, p. 276; and Gill, 1876, pp. 219-242). Macfarlane in his "Notes from New Guinea," *Athenæum*, 1876, p. 725, expresses his view concerning the ethnology of these people.

All we know concerning the ethnography of the **Fly River** valley is due to D'Albertis and Macgregor. The latter says (*C.*, 6323, 1891, p. 113): "I have seen no evidence of the existence of a race in the interior distinct from the coast tribes. Those seen at the boundary between British and German New Guinea were of a light colour; but that may not signify much. The dialects of the lower tribes differ from those of the upper in, as far as we know, every word. Of the structure of the languages we know nothing. . . . They all use the bow and arrow. They suffer from the

same diseases. There is not a clay pot on the Fly River. . . . They have the same large breed of orange-coloured dingo. . . . They are equally shy and timid, yet vivacious, excitable, and always doing very plucky things." All the lower part of the river is swampy. **Kiwai** is the largest island in the delta, the natives cultivate thirty-six kinds of bananas, twenty kinds of yams, ten kinds of sweet potatoes; they use eleven kinds of fibres and drain their gardens by ditches four yards apart. The men are quite naked (*cf.* D'Albertis, ii., pp. 18-21, 43, 51; Macgregor, *C. A.*, 105, 1890, pp. 36-43). A fairly complete reprint of the latter is given in *J. A. I.*, xxi., 1891, p. 75, and a shorter one in Thomson (pp. 117-121). Bevan's sensational account (1890, p. 258) of the cannibal habits of the Kiwai natives is criticised by Macgregor (*C. A.*, 105, 1890, p. 38).

Macgregor gives (*C. A.*, 105, 1890, p. 45) an interesting description of the village of **Odagositia**, fifty-one miles up the Fly River. One house was about 520 feet in length and more than 30 feet wide inside, the interior "was a perfect model of cleanliness and order". This is apparently the village which was looted by Mr. Chester and D'Albertis on board the *Ellangowan* (D'Albertis, ii., pp. 38-41). Between **Tagota**, where Macgregor was unprovokedly attacked (*loc. cit.*, p. 46), and Everill Junction there are very few natives. About 380 miles up the river is the "**Villaggio dei Cocchi**," in which D'Albertis collected (!) a couple of pigs and a large number of "interesting objects" (ii., pp. 131-137), and consequently Macgregor received a hostile welcome (*C. A.*, 105, 1890, p. 52). The most remarkable objects D'Albertis brought away were stone-clubs with perforated ornamental tops, wonderfully carved out of hard stone; nothing like them is known from elsewhere. D'Albertis (ii., pp. 85-89, 95-103), and Macgregor (*loc. cit.*, pp. 54-61) describe the upper reaches of the Fly River and the peculiar large houses made by the people.

**The country between the Fly and Aird Rivers** has been visited and mapped by Macgregor (*C. A.*, 1, 1892, pp.

49-54; *C. A.*, I, 1893, pp. 37-43), thus completing almost the last part of the coast hitherto unexplored; not much is yet known about the natives. Bevan gives a little information about the natives of the river to which he gave the absurd name of Queen's Jubilee River.

The ethnography of the **Gulf Papuans** has been largely described by Chalmers in 1885, **Orokolo**: method of counting, three legends, the origin of mankind, the story of Kanitu and a deluge myth (p. 163), *dubus*, dance-masks and a *Semese* dance (pp. 233-235). Three visits to the Papuan Gulf are described, pp. 133-154, 192-204, 224-238. In 1887 Chalmers describes **Maiupa**, pp. 58-68 (also *cf.* Thomson, J. P., *Le Village des Cannibales de Maipua*, *Rev. d'Ethnogr.*, vii., 1888, p. 391); **Orokolo**, pp. 69-75, these people are small in stature, especially the women, and are very like the Koriari tribe at the back of Port Moresby; **Maclatchie Point**, pp. 82-90; **Motu-Motu**, pp. 280-284. This last place is now called **Toaripi** by Chalmers; the latter is apparently the native name, whereas the former is the name given to the village by the Motu. Chalmers also now speaks of the Toaripi tribe; formerly he called it the Elema tribe; the latter may be a more general term than the former.

A chapter on "**Motu-Motu** and the customs of the people" is contributed by E. G. Edelfeld to Lindt's book (1887, p. 132); he and Bevan (1890, pp. 138, 139, 144) allude to these people as tall, well-built, very noisy, egoistic and quarrelsome. Stalwart, hirsute men similar to these occur generally from about the Aird River to Cape Possession; but there are smaller, also dark people, within and beyond these limits. A short distance up the **Alele** (Wickham River) "the population is composed of black and light coloured natives, all cannibals" (Chalmers, 1885, p. 143). Bevan describes the natives on the **Aurarmar** or Arvei River (p. 239), and gives a figure of them (1888, p. 17), and in the latter book (p. 15) a photograph and description of the chief of Omai: "A little black man, with twinkling black eyes and pleasant features". Lyne (pp. 68-95) and Thomson (pp. 81-87) also refer to Motu-Motu. A very

valuable summary of the more important customs and beliefs of the Toaripi is given by Chalmers (1890, pp. 311-317) and a list of their games (1887, *A.*, p. 68).

That part of the British Protectorate which extends from Cape Possession (lat. 8° 30′ S.) to Orangerie Bay (about 10° 30′ S.) may conveniently be termed **The Central District**. It contains a large number of tribes, which may be roughly grouped into three classes: (1) The Papuan Hill tribes, (2) the Melanesian colonists, and (3) the mixed tribes. Speaking in general terms the Melanesian immigrants occupy the great part of the coast as far as Redscar Bay, having driven inland the autocthonous population, but everywhere there has been more or less a mixture of the two peoples. Even among some of the hill tribes there appear to be traces of racial mixture. From about Redscar Bay, or Hall Sound, to Cape Possession it seems that the coast population is essentially Papuan with an admixture of Melanesian blood. The main tribes of this district are the Maiva and Kivori, Mekeo, and Roro.

1. **The Mixed Tribes.**— The **Maiva** country, just south of Cape Possession, is the southern limit of dance-masks (Chalmers, 1887, p. 50). These people use the large oblong wooden shield characteristic of the Toaripi. Chalmers (1885, pp. 135, 185, 271-275; 1887, pp. 241-244, 270-274) describes the people, their sacred houses, or *dubus*, etc., and a Maiva sorcerer (pp. 310-318). Stone (p. 186) has a short account of the people, and valuable information is given by Edelfeld (p. 131). **Mekeo** is the name given to the populous and fertile district up the Paumumu or St. Joseph River; a very interesting description of it is given by Macgregor (*C. A.*, 1, 1890, pp. 76-83; *cf.* abstract in *Journ. Anth. Inst.*, xxi., 1891, pp. 201-204). An account of the trouble caused by some of the tribes and how Macgregor quieted them will be found in *C. A.*, 1, 1892, pp. 19-21; *C. A.*, 1, 1893, pp. 15-22). Edelfeld (pp. 126-130) was the first to describe this district. The people are industrious and intelligent; near Nauea is a regular market place, where three or four tribes meet on certain days.

Fowls are kept in coops. They excel in fine network and make hammocks. It is probable that the Maiva and Mekeo are closely related tribes. **Roro** is the native name for Yule Island, and it is employed for the cognate mainlanders. Moresby gives the first description of these people (p. 177); other accounts will be found in D'Albertis, i., pp. 243-421; Stone, pp. 18-30, 186, 205, 230; Lyne, pp. 48-67; Chalmers, 1885, pp. 166-191, 271; Letters from Verius, Couppé and Navarre in Jouët, pp. 130-311, the chapter by Bishop Navarre on *Manners and Customs of New Guinea* is especially interesting.

2. **The Hill Tribes.**—Macgillivray (i., pp. 293-298), Gill (1876, pp. 242-263), and Moresby (p. 139) describe the natives of Redscar Bay. The **Kabadi**, who live at the back of the Bay, have been graphically described by Chalmers (1885, pp. 155-160; 1887, pp. 98-110, 119-123); *cf.* also Macgregor, *C. A.*, 1, 1892, p. 25. They with their allies the Doura have a blood feud with Koitapu, and "have long been notorious as a bad lot" (Macgregor, *C.*, 6323, 1891, p. 10). They and the Nara seclude their girls for a year or two when about twelve years old (Chalmers, 1885, p. 159; 1890, p. 319). The **Doura** are a miserable, small tribe that has suffered much at the hands of its neighbours (Chalmers, 1887, pp. 91-98). Macgregor (*C.*, 6323, 1891, pp. 9-13) visited this country and ascended the Vanapa River. He describes the chief as a man "with a decided Semitic face," and goes on to say that the Oriental cast of features is characteristic of the tribes of the interior. He describes (*C. A.*, 13, 1890, p. 38) a remarkable rattan suspension bridge, which is figured by Thomson. **The natives of the Owen Stanley Range** have been described by Macgregor, *C. A.*, 13, 1890, p. 41; they speak a Papuan dialect, and are physically stronger than the coast men, with rather broad and prominent cheek bones, Semitic nose, strong underjaw, very voluble; they do not tattoo nor wear nose ornaments, they wear caps made of cuscus fur (*cf.* also Macgregor, *Proc. Roy. Geogr. Soc.*, xii., 1890, p. 193). H. O. Forbes, *P. R. G. S.*, 1890, p. 562) believes that these belonged to the same tribe he met with; he gives a good de-

scription of the people and their clothing, etc., and a method of making fire by sawing with rattan, Lawes (*Proc. Roy. Geogr. Soc.*, v., 1883, p. 357) records a similar process used by the Koiari; and D'Albertis also described an analogous method of fire making near the source of the Fly River (ii., p. 99). Chalmers (1885, p. 162) met some squalid natives from the Yule Range; the men sleep in hammocks and are said to trade in shell ornaments with the coast natives of the north-east coast of the Protectorate. The best account of the **Koitapu** (**Koita** of Macgregor) is that by Lawes (p. 371). They live at one end of the Motu villages, but preserve their distinctness, or in villages a little way inland. There is little difference in physique between these two tribes, but the former is a little the darker. Chalmers (1887, p. 13) refers to the relations between them; it is interesting to note that the Motu usurpers have to pay spiritual tribute to the Koitapu sorcerers and buy fine weather from them. A good account of Koitapu sorceries, sacred stones, charms for wind and rain, yam planting and fighting is given by him in 1887, *A.*, pp. 58-62. The two tribes never fight now, but the Motu often help the Koitapu against their enemies. He also alludes to them on pp. 110-115 (1887); and in 1885, p. 151, refers to a legend which points to common origin for the Toaripi, the Koiari and the Koitapu; in a later version (1887, *A.*, p. 57) the Motu also have a joint origin with these; Turner also refers to them (pp. 472, 487). Romilly (1893, p. 321) describes a Koitapuan fire hunt or kangaroo drive. Lawes (p. 374) says the last two tribes are closely allied; he refers to their varied physiognomy. The **Koiari** villages are built on crests of hills, and in almost every village is one house high up on a tree. Macgregor (*C. A.*, 1, 1892, p. 27) attributes the more sturdy build of the Koiari to their mountain life and abundance of food. Stone (pp. 113-125, 129, 164-168) also describes the appearance of the Koiari, their houses, clothing, etc. Quite recently a very valuable account of Koiari customs is given by Chalmers (1890, pp. 317-323). Inland of the Koiari lies the country of the **Kupele** or **Kubere**. Chalmers (1885, p. 130) says some are very dark, others very light

coloured; they are allied to the Koiari. The Tabure and Sogeri are similar to the Koiari.

3. **The Melanesian Colonists.**—Of these immigrants the **Motu** have been most written about. Moresby (pp. 154-158) was the first to discover Port Moresby, which is the centre of the Motu tribe and has since become the capital of British New Guinea. The port was next visited by Gill (1876, p. 263); W. Y. Turner gives an extremely good account of the people, which is supplemented by Lawes. Stone's account will be found on pp. 46-97, 193, 203. Chalmers (1887, *A.*, pp. 63-68) describes Motu marriage and funeral customs, their religion and other matters; the legend (p. 57) pointing to a common origin with the Koiari, Koitapu and Elema (Toaripi) by no means adequately accounts for the ethnological relationships of the Motu. Elsewhere (1887) he devotes chap. ii. to a graphic account of the preparations for the annual trading voyage and chap. viii. to a comparison of Motu and Toaripi customs and beliefs. The Motu make great trading voyages to the Gulf of Papua in October, *i.e.*, at the end of the south-east monsoon, and return during the north-west monsoon. They voyage in *lakatois*, each of which consists of at least three canoes joined together and rigged with sails like crabs' claws. The Motu women make pottery, and as many as 30,000 pots will be exchanged in one year, for 150 tons of sago. A fleet of twenty *lakatois* would carry 600 men, and each man takes about fifty pots (Romilly, 1893, p. 257). The voyagers in some cases go to a distance of 200 miles. Lindt gives excellent photographs of these strange craft and an account of them and the method of sailing them (pp. 29-47). Lawes (1888) has made a scholarly study of the Motu language.

In his map Chalmers groups the **Hula**, **Kerepunu** and allied tribes under the name **Loyalupu**. These people closely resemble the Motu, but appear to be somewhat lighter in colour. Stone (p. 190), Gill (1885, p. 288), Chalmers (1887, p. 323; 1887, *A.*, pp. 63, 65), Lyne (pp. 102-122) and Lindt (p. 67), allude to these people; the women are even better tattooed than the Motu. An annual ceremony

at **Kalo** is noted in the *Arch. Rev.*, iv., 1890, p. 149. The neighbouring **Aroma** tribe is referred to by Gill (pp. 297-301). Koapena, the chief of Aroma, has the reputation of being the finest savage throughout a large district; he has been described by Chalmers (1887, pp. 274-280), Lyne (p. 114), Finsch (1885), Romilly (1889, pp. 177-181) and others.

The **Mailu** or **Mairu** according to Chalmers occupy the coast from Cloudy Bay to Orangerie Bay. Thomson (pp. 42-47) conveniently summarises Macgregor's accounts of his visit to this district; especially interesting is the Administrator's account (*C. A.*, 105, 1890, p. 29) of the stockaded villages of Merani and Isimari; the former is provided with two tree-houses which serve the double purpose of watch-towers and for the defence of wall and of the western gate, the most vulnerable part of the village. The Cloudy Bay people have long had an evil repute (Romilly, 1889, p. 60, and others), but Macgregor has now brought them to reason. Lyne (pp. 135-143) describes a visit to Mairu (Toulon Island); Chalmers has apparently applied the name of the island to the people living on the coast.

The district around Tauwara (Milne Bay) and the various archipelagoes off the south-eastern end of New Guinea appear to constitute a natural region to which I have elsewhere (1894) extended the term Massim (*cf.* Hamy, *Rev. d'Ethnogr.*, vii., 1888, p. 503).

For an account of the **Suau** (South Cape) natives see Chalmers and Gill, 1885, pp. 40, 51, 329, 334, Lyne, p. 166; the latter describes a cannibal feast in **Milne Bay** (p. 200). Moresby, who first discovered this bay, found the natives "friendly from the first" (p. 216). Finsch gives an account of this district (1888, pp. 262-273), so does Bevan (p. 89). The hill-tribes are noticed by Chalmers (1889, pp. 140, 143). **Awaiama** (Chads Bay), on the north side of the peninsula, was the scene of the murder of a trader named Ancell. This story, with the retribution which followed, is told by Baden Powell (1892, p. 147) and officially by Macgregor (*C.*, 5883, 1890, pp. 275-277, 297-301; *C. A.*, 1,

1892, pp. 10, 63), also J. P. Thomson (p. 34). The population is divided politically into districts that form independent federated communities, none of which have a high chief, nor, as a rule, does any village acknowledge the undisputed sway of any one man.

The islands from South Cape to Teste Island may conveniently be termed **The Moresby Group**. They are inhabited by the same people as on the neighbouring mainland and there is a great deal of intercommunication. Macgillivray (i., p. 253) gives an interesting account of **Tassai** (Brummer Island), and Baden Powell (p. 157) describes **Samarai** (Dinner Island); Finsch alludes (p. 277) to finding tattooed people here and in Rogea, a custom which he had not seen in Milne Bay or in the neighbourhood of the D'Entrecasteaux. The charnel houses and other particulars of **Rogea** (Heath Island) and **Sariba** (Hayter Island) are described by Macgregor (*C.*, 5883, 1890, p. 305); on p. 302 he states the **Tubutubu** (Engineer Group) people are great traders; they procure their fine (fifty feet long) sea-going canoes from Murua. Moresby (pp. 182, 188, 202), Bevan (p. 87), and others describe these islanders as copper-coloured. Chauvin ("Mémoire sur les Races de l'Oceanie," *Arch. des Miss. Scientif*, 3$^{me}$ sér., viii., p. 452) says: "In the series [of sixteen skulls] from the Engineer Group we can form two groups, especially if we pay regard to the character of the face". Hamy quotes (p. 511) Chauvin and compares his results with those of Comrie (1877, p. 102, and *cf.* Flower's *Catalogue*); in referring to the lighter coloured individuals who have been noticed by all travellers, the latter says the features and hair even in the lighter individuals remain unaltered. The best account of **Wari** (Teste Island) is by Finsch (1888, pp. 271-286); he describes the natives, their tattooing, making and trading of pottery; the canoes are imported from Murua, but are decorated with carving here.

**The Louisiade Group** consist of several large and numerous small islands, which are really a continuation of the axis chain of New Guinea. Macgillivray (i., pp. 168-250) gives an account of the previous exploration of the

group and adds much interesting information. Macgregor (*C. A.*, 1, 1892, p. 66) gives a very favourable picture of the inhabitants of **Pannaet** (Deboyne Island); they are active, intelligent, of good physique, and build the best canoes in the Possession; for this work they use adzes made of hoop iron, but sell the canoes for from ten to fifty stone axes. "They do not now use the stone axe as a tool in this part of the country, but it still represents the standard of currency in great transactions." The **Utian** (Brooker Island) are an aggressive and untrustworthy folk; they make clay pots. **Misima** (St. Aignan) is a large, mountainous and fertile island. The people are active, vivacious and industrious, but extremely untrustworthy. A large number of people associate together to make extensive gardens; having no sea-reef, there is no fishing. "They have entered the iron age and appear to have entirely given up the use of the stone axe except as a medium for purchasing wives" (Macgregor, *C.*, 5883, 1890, p. 249; *C. A.*, 1, 1892, p. 69; *C. A.*, 1, 1893, p. 32; and J. P. Thomson, p. 28). Basil Thomson (p. 533) noticed two types, "the one evidently Papuan, the other betraying strong Malay characteristics, such as the straight hair and not prominent features".

**Tagula** (Sudest) is the largest island of the group. J. P. Thomson (p. 15) refers to depredations wrought in this island by "the wild cannibal head-hunters of Brooker Island". Macgillivray (i., pp. 186-241) describes a couple of neighbouring islets. The furthest island is **Roua** (Rossel Island); it was here that the *St. Paul* was wrecked in 1858 with 327 Chinese emigrants on board, of whom all but one are said to have been massacred and eaten in about two months (*cf.* V. de Rochas, "Naufrage et Scènes d'Anthropophagie a l'Île Rossel," etc., *Tour de Monde*, 2$^{me}$ sem., 1862, p. 14). Macgregor (*C.*, 6323, 1891, p. 197) says the people "are perhaps the most harmless and inoffensive in the Possession. . . . They are not tattooed. . . . The women are very clever at basket making. . . . The men carry sponges to wash their faces with." Elsewhere (*C.*, 5883, 1890, p. 245) he says: "They have no pottery.

. . . The natives differ from those of the mainland, resembling in appearance a mixture of the Motu native and of the New Hebrides native." Basil Thomson (1889, p. 532) says: "Their appearance suggests a hybrid between the Papuan and the natives of the Solomon Islands. . . . They are short and robust, of sooty-brown complexion, with a flat nose, wide nostrils and markedly prognathous."

**The D'Entrecasteaux Group** consists of Duau (Normanby Island), Moratau (Ferguson Island), Goodenough Island and a few small islands. The large islands are mountainous, very steep and fertile; as there are no fringing reefs very little fishing is done, so the people are driven to agriculture, at which they are very expert, making terraces on the mountain sides. All the natives appear to be head-hunters. Moresby (p. 245) found them very friendly. "The Papuan type is well seen in" the natives of **Duau.** "There can be no doubt that the most advanced of them, those of the east end, are head-hunters. The inhabitants of the southern part of the island are very ready to trade. . . . Those of the central portion have no idea whatever of trade, and those of the north end have a less productive country and do not seem to possess the energy of those in the south" (Macgregor, *C. A.*, 13, 1890, p. 11; also *C. A.*, 1, 1892, p. 63; *C. A.*, 1, 1893, p. 23). Basil Thomson (p. 536) came across two tribes in the north not ten miles apart, one of which would barter all they possessed for tobacco, while the other did not know its use. The natives of **Moratau**, the largest of the group, are keen traders and have large canoes (Macgregor, *C. A*, 1, 1892, p. 65; 1893, p. 2; B. H. Thomson, p. 536). The Goodenough islanders are a friendly, undemonstrative people who make clay pots. "They are practically an inland or 'bush tribe'" (B. H. Thomson, p. 540). Sergi describes a large number of skulls from Dawson Strait.

The principal island of **The Trobriand Group** is **Kiriwina.** Only one language is spoken in the group; social matters are on quite a different footing from elsewhere in the Protectorate. It is very seldom that a woman or a boy

approaches a chief except in a crouching attitude; the chief is listened to and treated with respect. On the whole the women have less influence and have much less to say than is the case in many of the ruder tribes on the mainland. This is apparently a consequence of the superior position of the chief. They are a very hospitable people and presented Sir William Macgregor with quantities of cooked food in large wooden dishes; "nothing like this occurs on the mainland". They are skilful wood-carvers and keen traders. Their only weapons are spears, and short, double-edged clubs (*C. A.*, 1, 1892, p. 7; 1893, pp. 3-7, 28-30, and *J. A. I.*, xxi., 1892, p. 481; also Finsch, 1888, p. 205; Hamy; and Haddon, "Wood-carving in the Trobriands," *Illust. Archæologist*, i., 1893, p. 107).

**Murua** is by far the largest island of the small **Woodlark Group**. The first accounts of this island were given by Fathers Montrouzier (*Ann. p. l. Propog. d. l. Foi*, xxii., 1850, p. 88) and Thomassin (*l. c.*, xxv., 1853, p. 390). I have translated their most important observations in *Folk-lore*, 1894. Salerio refers to the people; he describes them as short, powerful; their skin colour is from pale yellow to chestnut brown; they are more friendly and less savage than the natives of the Louisiades (*Petermann's Mittheil.*, 1862, p. 343, with a good map on pl. xii.). Romilly (1886, p. 127) describes a visit to the island; he was struck with the good looks of the women; some of the men were dwarfish, they were of a light copper-colour. Macgregor (*C. A.*, 1, 1892, p. 4) formed a favourable opinion of the people—they are active and enterprising. The stone adze has quite disappeared; other details are also given. Sergi describes a number of skulls from Murua.

The natives of the **Laughlan Islands**, **Nada**, "are precisely the same (as those of the Woodlarks), and the same as the Papuans of the east coast of New Guinea. . . . They are extraordinarily friendly and never fight" (Romilly, 1886, p. 130). For a valuable account of native customs and traditions by W. Tetzlaff, see *C. A.*, 1, 1892, p. 104 (reprinted in *J. A. I.*, xxi., 1892, p. 483), *cf.* also Macgregor, *loc. cit.*, p. 9, and *Proc. Roy. Geogr. Soc.*, xiii., 1891, p. 177.

There is at present very little information respecting the natives of **the north-eastern coast** of the Possession. Captain Moresby was the first to explore this coast, and he gives a few notes on the natives. Macgregor (*C. A.*, 1, 1892, pp. 11, 63) gives more details near **Cape Sebiribiri** (Cape Vogel); the natives are beginning to learn the use of tobacco and iron; they cook in profusely ornamented wide-mouthed clay pots. In **Collingwood Bay** "they did not understand the use of iron and had no wish to obtain any, of tobacco they were, of course, quite ignorant, and we found that the pieces of bamboo they carried were used exclusively as nose flutes". Moresby describes these people as dark and dirty-looking. Along this coast, according to Macgregor, the natives use disc-shaped stone clubs, spears and shields; they chew the betel, "but possess none of the dexterity in carving limespoons, etc., so conspicuous in the Trobriand Group. . . . They do not tattoo." Many wear the hair in long matted ringlets, some of the men wear false whiskers; they make elaborate corsets of net and inwoven Job's tears.

## BIBLIOGRAPHY.

BEARDMORE, E. (1890). The Natives of Mowat, Daudai, New Guinea. *J. A. Inst.*, xix., p. 459 (with additional notes).

BEVAN, T. F. (1888). *Mr. Theodore F. Bevan's Fifth Expedition to British New Guinea: Preliminary Presentation Pamphlet* (illustrated). Sydney.

BEVAN, T. F. (1890). *Toil, Travel and Discovery in British New Guinea.* London. (*Cf.* also *Proc. Roy. Geogr. Soc.*, 1887, p. 595; 1889, pp. 82, 90.)

CHALMERS, J., and GILL, W. WYATT (1885). *Work and Adventure in New Guinea*, 1877-1885. London.

CHALMERS, J. (1887). *Pioneering in New Guinea.* London.

CHALMERS, J. (1887 A). On the Manners and Customs of some of the Tribes of New Guinea. *Proc. Phil. Soc. Glasgow*, xviii., p. 56.

CHALMERS, J. (1890). Report on the Toaripi and Koiari Tribes. *Report Austral. Assoc. Advanc. Sci.*, ii., pp. 311-323.

CLERCQ, F. S. A. DE, and SCHMELTZ, J. D. E. (1893). *Ethnographische Beschrijving van de West-en Noordkust van Nederlandsch Nieuw-Guinea.* Leiden, P. W. M. Trap.

COMRIE, P. (1876). Anthropological Notes on New Guinea. *J. A. I.*, vi., p. 102.

COUPPÉ, L. *Cf.* Jouët.

D'ALBERTIS, L. M. (1880). *New Guinea: What I did and what I saw.* London. (*Cf. J. Ant. Inst.*, vi., 1886., p. 216.)

EDELFELD, E. G. (1887). *Travels in the Neighbourhood of Mount Yule. Cf.* Lindt, p. 126.

FINSCH, O. (1883). Anthropologische Ergebnisse einer Reise in der Südsee und dem malayischen Archipel in den Jahren, 1879-1882. *Zeits. f. Ethnol.*, Suppl.

FINSCH, O. (1885). Ueber Bekleidung, Schmuck and Tätowirung der Papuas der Südosküste von Neu-Guinea. *Mitt. d. Anth. Ges. Wien*, xv.; translated in *Rev. d'Ethnogr.*, v., 1886, p. 49.

FINSCH, O. (1887). Hausbau, Häuser und Siedelungen an der Südostküste von Neu-Guinea. *Mitt. d. Anth. Ges. Wien*, xvii., p. 1.

FINSCH, O. (1888). *Samoafahrten: Reisen in Kaiser Wilhelms-Land und Englisch-Neu-Guinea in den Jahren* 1884, *u.* 1885. Leipzig: F. Hirt & Sohn.

FINSCH, O. (1888 A). *Ethnological Atlas: Types from the Stone Age of New Guinea.* Leipzig: F. Hirt & Sohn.

FINSCH, O. (1888 B, 1891). Ethnologische Erfahrungen und Belegstücke aus der Südsee. *Annal. des k. k. naturhist. Hofmus.*, Vienna, A. Hölder. New Guinea: (1) British New Guinea, (*a*) South-east Coast, vol. iii. (1888), pp. 293-364; (*b*) East Cape and D'Entrecasteaux Islands, vol. vi. (1891), pp. 13-33; (*c*) Trobriand, pp. 33-36; (2) Kaiser Wilhelms-Land, pp. 37-130.

FORBES, H. O. (1890). The Owen Stanley Range, New Guinea. *Proc. Roy. Geogr. Soc.*, xii., p. 562.

FLOWER, W. H. (1879). *Catalogue of Museum of Royal College of Surgeons:* i., *Man.*

GILL, W. WYATT (1876). *Life in the Southern Isles.* London.

GILL, W. WYATT (1885). *Cf.* Chalmers.

HADDON, A. C. (1890). The Ethnography of the Western Tribe of Torres Straits. *J. Ant. Inst.*, xix., p. 297.

HADDON, A. C. (1890). Legends from Torres Straits. *Folk-lore*, i., pp. 47-81, 172-196.

HADDON, A. C. (1891). The Tugeri Head-Hunters of New Guinea. *Internat. Arch. f. Ethnogr.*, iv., p. 177.

HADDON, A. C. (1893). The Secular and Ceremonial Dances of Torres Straits. *Ibid.*, vi., p. 131.

HADDON, A. C. (1894). The Decorative Art of British New Guinea: a Study in Papuan Ethnography. *Cunningham Memoir*, x., *Roy. Irish Acad.* (in the Press).

HADDON, A. C., and RAY, S. H. (1893). *Cf.* Ray.

HAMY, E. T. (1888). Étude sur les Papouas de la Mer d'Entrecasteaux. *Rev. d'Ethnogr.*, vii., p. 503.

HAMY, E. T., and QUATREFAGES. (1882). *Cf.* Quatrefages.

JOUÈT, V. (1887). *La Société des Missionaires du Sacré-Cœur dans les Vicariats apostoliques de la Mélanésie et de la Micronésie.* Issoudun.

JUKES, J. B. (1847). *Narrative of the Voyage of H.M.S. "Fly".* London.

LAWES, W. G. (1879). Ethnological Notes on the Motu, Koitapu and Koiari Tribes of New Guinea. *Journ. Anth. Inst.* viii., p. 369.

LAWES, W. G. (1388). *Grammar and Vocabulary of Language spoken by Motu Tribe (New Guinea).* with introduction by the Rev. G. Pratt. Sydney: C. Potter.

LINDT, J. W. (1887). *Picturesque New Guinea.* London.

LYNE, C. (1885). *New Guinea.* London.

MACFARLANE, S. (1876). Notes from New Guinea. *Athenæum*, No. 2562, p. 725.

MACGILLIVRAY J. (1852). *Narrative of the Voyage of H.M.S. "Rattlesnake".* London.

MACGREGOR, W. (1890). Journey to the Summit of the Owen Stanley Range, New Guinea. *Proc. Roy. Geogr. Soc.*, xii., 1890, p. 193.

MACGREGOR, W. Despatches and Reports in the following:—

Annual Report on British New Guinea, Brisbane, *C. A.*, 13, 1890 (4th September, 1888, to 30th June, 1889); *C. A.*, 105, 1890 (1st July, 1889, to 30th June, 1890); *C. A.*, 1, 1892 (1st July, 1890, to 30th June, 1891); *C. A.*, 1, 1893 (1st July, 1891, to 30th June, 1892).

Further Correspondence respecting New Guinea, London. *C.*, 6323, 1891 (contains pp. 37-48 of *C. A.*, 13, 1890; pp. 25-93 of *C. A.*, 105, 1890; and pp. 1-18 of *C. A.*, 1, 1892); *C.*, 5883, 1890 (July, 1885, to July, 1889).

All the important reports of official explorations and administrative duties published in the White Colonial Annual Reports are reprinted in the Blue Books ("Further Correspondence") with the exception of certain sketches and a very valuable series of maps, vocabularies and scientific appendices, all of which occur only in the former series. In the Blue Books are a number of letters and other matters of an administrative nature which throw light on various aspects of the relations of the white race with the natives, missionary efforts and so forth.

MANTEGAZZA, P. (1877). Studii antropoligici ed etnografici sulla Nuova Guinea. *Arch. p. l'Antrop. e la Etnol.*, vii., p. 1.

MEYER, A. B. (1889). Masken von Neu Guinea und dem Bismarck Archipel. *Königl. Ethnogr. Mus. z. Dresden*, vii.

MORESBY (1876). *Discoveries in New Guinea.* London.

NAVARRE, L. *Cf.* Jouët.

NISBET, HUME (1891). *A Colonial Tramp*, vol. ii. London.

PARTINGTON, J. EDGE, and HEAPE, C. (1890). *Ethnographical Album of the Pacific Islands.* Manchester: J. C. Norbury.

POWELL, B. F. S. BADEN (1892). *In Savage Isles and Settled Lands.* London.

QUATREFAGES and HAMY, E. T. (1882). *Crania Ethnica.* Paris.

RAY, S. H. (1894). The Languages of British New Guinea. *Journ. Anth. Inst.*, xxiv., 1894, p. 15; an amplification of (1893) *Trans. Ninth Internat. Congress Orientalists*, London, 1892, ii., p. 754.

RAY, S. H., and HADDON, A. C. (1893). A Study of the Languages of Torres Straits, with Vocabularies and Grammatical Notes, Part i. *Proc. Roy. Irish. Acad.* (3), ii., p. 463.

ROMILLY, H. H. (1887). *The Western Pacific and New Guinea.*

ROMILLY, H. H. (1889). *From my Verandah in New Guinea, Sketches and Traditions.* London.

ROMILLY, H. H. (1893). *Letters from the Western Pacific and Mashonaland*, 1878-1891. London.

RYE, E. C. (1884). Bibliography of New Guinea. *Roy. Geogr. Soc. Suppl. Papers*, i.

SCHMELTZ, J. D. E. *Cf.* Clercq.

SERGI, G. (1892-3). Die Menschenvarietäten in Melanesia. *Arch. f. Anthropol.*, xxi., p. 339. Le Varietà umane della Melanesia. *Boll. Roy. Accad. Med. Roma*, xviii.

STONE, O. C. (1880). *A Few Months in New Guinea.* London.

TETZLAFF, W. (1892). Notes on the Laughlan Islands. *Ann. Rep. Brit. New Guinea ; C. A.*, 1, 1892, p. 104 : reprinted in *Jour. Anth. Inst.*, xxi., p. 483.

THOMAS, OLDFIELD (1885). Account of a Collection of Human Skulls from Torres Straits. *Journ. Anth. Inst.*, xiv., 1885, p. 328 ; *cf.* also (1884) *Report on the Zoological Collections, Voyage of H.M.S. "Alert,"* 1881-82 (two skulls from Naggir).

THOMSON, BASIL H. (1889). New Guinea : Narrative of an Exploring Expedition to the Louisiade and D'Entrecasteaux Islands. *Proc. Roy. Geogr. Soc.*, xi., pp. 525-542, and map.

THOMSON, J. P. (1892). *British New Guinea.* London.

TURNER, W. Y. (1878). The Ethnology of the Motu. *Jour. Anth. Inst.*, vii., p. 470.

TURNER, W. (1880). Two Masks and a Skull from Islands near New Guinea. *Jour. Anat. and Phys.*, xiv., p. 475.

VÉRIUS, S. H. *Cf.* Jouët.

## KAISER WILHELMS-LAND.

The following works on German New Guinea should be consulted ; a very complete bibliography is given by De Clercq and Schmeltz. Dr. O. Finsch's *Samoafahrten* may be regarded as the indispensable text-book of that district ; his *Atlas* also illustrates many objects from the German coast, see also pp. 37-130 *Ann. k. k. nat. Hofmuseums. Wien*, iii., 1888, and Partington's *Album.* Dr. O. Schellong has made a number of valuable investigations among the natives ; in his paper, Ueber die Herstellung einiger Ethnographica der Gegend Finschhafens, *Int. Arch. f. Eth.*, i., 1888, p. 220, he gives an illustrated account of the manufacture of beads from small shells, of bark cloth, and of small tortoise-shell earrings. There is a paper on Musik und Tanz der Papuas in *Globus* (1889), p. 81, and a very important study of the ceremonies of the circumcision of the lads, which constitute their initiation into manhood, Das Barlum-fest der Gegend Finschhafens (Kaiser Wilhelms-Land) : ein Beitrag zur Kenntniss der Beschneidung der Melanesièr (*Int. Arch. f. Eth.*, ii., 1889, p. 145). He published in the same year another valuable paper on family life and customs, Ueber Familienleben und Gebräuche der Papuas der Umgebung von Finschhafen (K. W.-L.), *Zeits. f. Ethnol.*, xxi., 1889, p. 10. Many of the observations made by Schellong are also interesting from a medical point of view, as there is a good deal of physiological detail in this paper. In vol. xxiii., 1891, p. 156, of the same journal is a paper by Schellong entitled Beit-

räge zur Anthropologie der Papuas; *cf.* also Die Eingeborenenbevölkerung (Papua's) von Kaiser Wilhelms-Land und dem Bismarck Archipel, *Beit. zur Allgem. Ztg.* (München), Nos. 46 and 48, 1889. Varied information and some papers of interest will be found in the *Nachrichten über Kaiser Wilhelms-Land und dem Bismarck Archipel* from the commencement in 1885. The following is the full title of H. Zöller's book, *Deutsch-Neuguinea und meine Ersteigung des Finisterre-Gebirges. Eine Schilderung des ersten erfolgreichen Vordringens zu den Hochgebirgen Inner Neuguineas, der Natur des Landes, der Sitten der Eingeborenen und des gegenwärtigen Standes du deutschen Kolonisation-sthätigkeit in Kaiser-Wilhelms-Land, Bismarck- und Salomon-Archipel, nebst einem Wortverzeichniss von 46 Papua-Sprachen*, 1891. Baron N. von Miklucho-Maclay, who lived among the natives of the Malay coast (Astrolabe Bay and its neighbourhood) for a long time, has unfortunately published very little; the following notes of his embody some of his observations: Schädel und Nasen der Eingeborenen Neu-Guineas, *Zeits. f. Ethnol.*, v., 1873, verhandl., p. 188; Die Brachycephalie der Papuas in Neu-Guinea, *Zeits. f. Ethnol.*, vi., 1874, p. 177; Einige Worte über die sogennante "gelbe Rasse" im Süd—Osten Neu-Guineas, *Zeits. f. Ethnol.*, xii., 1880, pp. 90, 375; *cf.* also *Zeits. f. Ethnol.*, x., 1878, pp. 111, 116; xiv., 1882, p. 576; *Nature*, xxi., p. 227.

## NETHERLANDS NEW GUINEA.

The most important work on Dutch New Guinea is a recently published memoir by F. S. A. de Clercq and J. D. E. Schmeltz entitled *Ethnographische Beschrijving van de West-en Noordkust van Nederlandsch Nieuw-Guinea*, Leiden, P. W. M. Trap, 1893. As this work must be consulted by any student of that portion of New Guinea, and as it contains such a complete bibliography, there is no need for me to copy out the titles of the works therein recorded. Most of the information respecting New Guinea in works on general anthropology and ethnology refers more particularly to the northern part of that island, since explorers like Wallace, Beccari, D'Albertis and Hartog, and vessels such as the *Challenger* and the *Marchesa*, have approached New Guinea from the Malay Archipelago. Prince Roland Buonaparte has several times epitomised the discoveries of Dutch travellers (*Bull. Soc. Géogr. Paris*, 1884, p. 530; *Soc. de Géogr. de Paris, C. R.*, 1885, p. 165, and separate publications in 1882 and 1886). The series of papers by A. B. Meyer, Ueber Hun-

dert fünf und dreissig Papua-schädel von Neu Guinea und der Insel Mysore (Geelvinksbai), *Mitth. ad K. Zoolog. Mus. Dresden*, i., 1875 ; ii., 1877 ; iii., 1878, and the other papers in that publication are important contributions to Papuan physical anthropology, as is Gabelentz and Meyer's Beiträge zur Kenntniss der Melanesischen Mikronesischen and Papuanischen Sprachen, *Abhandl. d. Phil. Hist. Cl. d. König. Sach. Gesel.*, viii., 1882, p. 375, from a linguistic point of view. It should be remembered that Schmeltz's bibliography is supplementary to that of Rye.

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